Technische Universität München
Fakultät für Architektur

ISBN 978-3-941370-49-4

smartTES

Innovation in timber construction for the modernisation of the building envelope

Book 5
Fire safety

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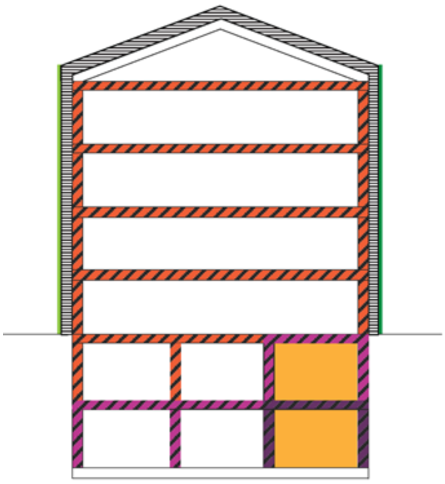

10.03.2014

Acknowledgements

"smartTES – Innovation in timber construction for the building modernization" is a transnational research project under coordination of the WoodWisdom-Net and funding distributed by national funding agencies.
Duration 2010-2013

Partners

Germany

- Technische Universität München,
  Lehrstuhl für Holzbau und Baukonstruktion, Prof. Dr.-Ing. Stefan Winter
  Fachgebiet Holzbau, Prof. Hermann Kaufmann
- Hochschule Rosenheim
- B&O Wohnungswirtschaft
- Gumpp & Maier GmbH
- Ambros GmbH
- Funding: BMBF

Finland

- Aalto University
- Finnish Real Estate Federation (Suomen Kiinteistöliitto ry)
- Finnish Wood Research Oy
- Metsä Wood
- Puuinfo Oy
- PAK RAK Oy
- Funding: TEKES

Norway

- SINTEF
- NTNU Norwegian University of Science and Technology
- Funding: The Research Council of Norway

Project coordination: Dipl.-Ing. Frank Lattke

www.tesenergyfacade.com

Publisher

Technische Universität München
Fakultät für Architektur
Arcisstr. 21, 80333 München
www.ar.tum.de, verlag@ar.tum.de

ISBN 978-3-941370-49-4

Public funding by

SPONSORED BY THE Federal Ministry of Education and Research

Tekes

The Research Council of Norway

Contents

Literature

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Abbreviations and Units

Abbreviations

AR	Habitable room
DG	Attic-storey / Top floor
BKL	Brannklasse (Fire class)
BW	Fire wall
GK	Gebäudeklasse (Building class)
KG	Basement
LBS, main	TES-Façade part of main load-bearing structure
LBS, secondary	TES-Façade part of secondary load-bearing structure, not stabilizing the main structure.
MBO	Musterbauordnung (German Model Building Regulation)
NE	Unit-of-use
NF	Necessary corridor
NTR	Necessary stairwell
P	Fire class, Finland
RG	Regular Floor
TES	TES EnergyFaçade - timber based element system for improving the energy efficiency of the building envelope

The contents of smartTES work package 1.5 are based on work done in the research project “TES EnergyFaçade”. In the final report from "TES EnergyFaçade", under the title “Fire Safety of Façades”, the basic fire safety objectives for inhabited buildings are listed [1]. Spread of fire scenarios and critical joints in case of fire spread are visualized. Schematic solutions for the integration of fire stops, which are required using combustible insulation material inside the TES-Façade elements, are given. The Finnish and German fire safety regulations for the TES Energy-Façade and a European overview of fire safety testing of facades are presented in a short summary.

The topic of fire safety requirements has been continued within the research project SmartTES. In addition to the basic TES-Façade the fire safety requirements for spatial extensions like rooftop extensions, annexes, or balconies have been summarized. A building extension might cause a change in building class which consequently has an effect on the fire safety requirements for the entire building. Therefore, an overview has been developed in which, basic TES-Façade fire safety requirements are illustrated together with the consequences of various retrofitting measures on the entire building. The overview covers Finnish, German, and Norwegian fire regulations. The characteristics of different national requirements are compared with each other as to illustrate the national individual approaches within the European fire safety regulation landscape.

Critical junctions and the window-opening have been studied closely. Detail solutions have been developed and examined in computational simulations and real fire tests. After testing various construction details in orientating small-scale fire tests in a furnace, a full-scale fire test was performed. The test results are shown in the following. In conclusion, recommended, exemplary construction details are given. [41]

1. Fire regulations – Overview and comparison

1.1. National requirements - Comparison

By comparing the national requirements of Finland, Germany and Norway, the clearly different regulation systematics within Europe becomes obvious. Although the standard European classification notation (according to EN 13501) has been harmonized and implemented in all three countries, enabling a European-wide product applicability with one and the same technical approval (ETA), the field of application differs partially. Table 1 summarizes component requirements for a TES-Façade as (part of) an exterior wall with either fire-separating functions only or additional load-bearing functions, and the material requirements for the cladding surface.

In Finland, buildings are categorized in three building fire classes (P1, P2 and P3). The fire classes are defined by building height, gross floor area, floor count and building occupancy. Within fire classes P1 and P2 there is further differentiation for the load bearing and fire separation requirements based on the expected fire load.

In Germany, buildings are categorized in five building classes (Gebäudeklasse 1-5). Buildings are categorized based on the height of the highest floor level, the size of their units of use (Nutzungseinheiten), type of occupancy and position next to other buildings.

In Norway, buildings are categorized in six Risk classes (Risikoklasse 1-6) and four Fire classes (Brannklasse 1-4). The Risk class is based on the threat a fire can entail in relation to danger to life and health. The Risk classes shall provide a basis for design and construction to ensure escape and rescue in case of fire. The Fire class is based on the consequences a fire can entail in relation to danger to life, health, social interests and the environment. The Fire classes shall provide a basis for design and construction to ensure the structure's load bearing capacity in case of fire. Buildings are categorized based on their utilization and number of floors. The Norwegian Technical Regulations do not quantify the fire resistance of building components, but describes the quality of it. *The fire resistances given in Table 1 are therefore not absolute requirements, but pre-qualified fire performances given by the Guideline to the Technical Regulations*. Materials or building components with other fire performances, for example combustible materials in load bearing or separating walls for buildings in BKL 3, can be used if documentation shows that the solution meets the requirements given in the Technical Regulations.

FINLAND	Building class	**P3**	**P2**			**P1 (single floor rooftop extension)**	**P1**					
Specificaton	Height	small buildings ≤ 2 floors	≤ 8 floors ≤ 26 m			total height including extension ≤ 8 floors ≤ 26 m	building height ≤ 2 floors			3 - 8 floors ≤ 26 m		
	Fire Load [MJ/m²]		< 600	600 - 1200	> 1200	< 600 only	< 600	600 - 1200	> 1200	< 600	600 - 1200	> 1200
TES-Facade	Fire-Separating	-	-	-	-	-	-	-	-	-	-	-
	Loadbearing		R 60	R 120	R 180	R 60	R60	R90	R120	Load bearing TES Facade not possible (A2-s1, d0 materials required)		
Cladding	External surface from 2. storey	-	B-s2, d0 or D-s2, d2 with additional constructive requirements			D-s2, d2	B-s1, d0 in general, B-s2, d0 in apartment & workplace buildings, certain parts D-s2, d2 with additional constructive requirements					
	External surface in ground level and above & below the fire exits at the facade		B-s2, d0			-	B-s1, d0 in general B-s2, d0 in apartment & workplace buildings					
	Insulation		A2-s1, d0			A2-s1, d0	A2-s1, d0					
	Internal surface of the ventilation gap (wind barrier)		A2-s1, d0			B-s1, d0	B-s1, d0					

GERMANY	Building class	**GK1**	**GK2**	**GK3**	**GK4**	**GK5**
Specification	Height	1-3 floors (≤ 7 m)			4-5 floors (≤ 13 m)	6-8 floors (≤ 22 m)
	Unit-of-Use (NE)	≤ 2 units in Σ ≤ 400 m²		-	each unit ≤ 400 m²	-
	Position	detached	attached	-	-	-
TES-Facade	Fire-Separating	-			EI 30-ef$_{(o\rightarrow i)}$ E 30$_{(i\rightarrow o)}$	EI 30-ef$_{(o\rightarrow i)}$ E 30$_{(i\rightarrow o)}$
	Loadbearing (column/wall)	-	R/REI 30	R/REI 30	R/REI 60 $K_2$60 and insulation in A2-s1,d0	R/REI 90 A2-s1,d0
Cladding	Surface and Insulation	E-d2			C-s3, d0 (B1)	
	Subconstruction				C-s3, d0 (B1) or E-d2 (B2) + compensation measures (fire stops)	

NORWAY	Fire class	**BKL1**	**BKL2**	**BKL3**		**BKL 4**
Specification	**Risk class 1-4**	1-2 floors	3-4 floors	≥ 5 floors (RC1 -> BKL2)		≥ 16 floors, Chemical industry, fire hazardous materials, etc.
	Risk class 5	1 floor	2 floors	≥ 3 floors		
	Risk class 6	1 floor	2-4 floors	≥ 5 floors		
	Height	≤ 9 m	≤ 9 m	> 9 m		
	Loadbearing Structure	Snd. / Main	Snd. / Main	Secondary	Main	
TES-Facade	Fire-Separating	EI 30	EI 60	EI 60 A2-s1,d0		
	Loadbearing	R 30	R 60	R 60 A2-s1, d0	R 90 A2-s1, d0	
Cladding	Surface	D-s3, d0	B-s3, d0			

Table 1 Brief overview of national fire safety requirements for façade elements (Finland, Germany, and Norway)

1.2. Overview Finland (Tulamo)

Fire regulations

The Finnish fire regulations are presented in the National Building Code of Finland, Chapter E1, 2011, as defined by the Finland's Ministry of the Environment. The profound technical requirements are:

- In the case of fire, the load-bearing constructions of the building must sustain for the imposed minimum duration of time;
- The generation and spread of fire and smoke in the building must be limited;
- The spread of fire to neighbouring buildings must be limited;
- The occupants in a building must be able to leave the building or be rescued by other means;
- The safety of the rescue teams in the building must be taken into consideration. [2]

The fire safety requirements are met if the building is designed and built according to the fire classes and numerical criteria provided by the regulations and guidelines stated in the National Building Code of Finland. The fire safety requirements are also met, if the building is designed and built based on simulated fire scenarios, which cover the conditions which are likely to occur in the relevant building. Meeting the requirements is proved by case-by-case simulations considering the use and properties of the simulated building. As the simulation is done for each building individually, this research is focusing only on the numerical criteria stated in the National Building Code of Finland. [3]

The general requirement of fire regulations is that the spread of fire from one building to another should not endanger life safety or cause unacceptable property losses or social consequences. In apartment buildings, each apartment forms its own fire compartment. Also the function of the space defines fire boundaries between clearly different functions e.g. technical spaces. The exterior wall does not usually function as a fire separating building element, although there are structural requirements for load bearing walls. [4]

Fire classes

The National Building Code of Finland classifies the buildings into one of the three fire classes P1, P2 or P3. The fire classes are defined by building height, gross floor area, floor count and building occupancy. The fire class P1 has the strictest requirements. Fire class P3 has fewer requirements and it is mostly applied in small buildings up to two stories. Basic information for the fire class definitions are listed below.

P1 - In fire class P1 buildings, the load-bearing constructions are assumed, as a rule, to withstand fire without collapsing. The size of the building and the number of occupants are not restricted.

P2 - The fire class P2 includes a limitation on building height, and the number of occupants depending on the type of the building. Required properties for wall, ceiling and floor surface materials are also described. Fire class P2 is divided further into subcategories based on building height and floor count.

P3 - In fire class P3 there are no special requirements concerning fire resistance for the load bearing constructions. A sufficient level of fire safety is achieved by restricting the size of the building and the number of occupants depending on the use of the building. The maximum building height for apartment buildings is either 2 floors or 9 metres.

Different parts of a building may belong to different fire classes provided that the spread of fire is prevented by a firewall. [5]

TES-Façade - Fire safety requirements
TES Façade elements can be used both loadbearing and non-loadbearing exterior wall of the buildings that have fire classes P3 or P2, provided that the TES-Façade elements meet the requirements stated for fire classes P3 and P2 respectively in the The National Building Code of Finland explained in Figures 2, 3 and 4. TES Façade elements can be used as a load bearing exterior wall in P1 class buildings up to 2 floors and non-loadbearing exterior wall in P1 class building up to total height of 8 floors providing that the insulation is made minimum of A2-s1, d0 class products. Load bearing exterior wall frame in P1 class buildings higher than 2 floors must be made from minimum A2-s1, d0 class products and therefore TES Façade elements cannot be used in that situation. The material surface requirements for exterior wall are described in the table 1.

Horizontal TES-Extensions – Fire safety requirements
Horizontal extensions can be divided into light exterior structures such as balconies and deck access systems which are added to the existing building, and heavier extensions which are adding to the building's heated area and the floor area which is calculated for the building licence. The light extensions are treated as additional parts to the existing building and the fire safety requirements are based on the existing building fire class requirements. Extensions which add heated area to the building are treated according to two possible scenarios. If the extension is not separated from the existing building with a firewall, and it shares the escape routes with the existing building, then the fire requirements are defined by the properties of the existing building and the size of the horizontal extension. If the extension is separated with a firewall and has its own separate fire exits, it is treated as a new, separate building and the fire class can differ from the existing building.

Vertical (rooftop) TES-Extensions – Fire safety requirements
The fire regulations and requirements for rooftop extensions on apartment buildings are based on the existing building fire class, building floor count and building height. The fire regulations allow rooftop timber based extensions up to a maximum floor count of 8 floors including the ground floor.

The National Building Code of Finland states special regulations for P1 class buildings permitting a single additional rooftop apartment floor made of D-s2,d2 class material, such as wood, without the need of a sprinkler system. The buildings' total floor count must not exceed 8 floors, including the ground floor and extension floor. The maximum building floor height is 26 metres. The total fire load of the new extension must be under 600MJ/m². The external wall surfaces and the exterior surface of the ventilation gap can be of D-s2,d2 class material, such as wood. If the exterior cladding is made of D-s2,d2 class material, the eaves of the extension structure must meet EI30 requirements as to prevent fire spread from the exterior façade to the attic. The wind barrier material must be of class B-s1,d0. Insulation materials must be from class A2-s1,d0 products. Load bearing structures can be made from class D-s2 d2 products, except for the walls of fire exits, for which is required A2-s1,d0 products for load bearing structures. The load bearing structures require 60 minutes load bearing capacity (R60) and the structures must be covered inside the building with claddings of class $K_2$30 materials. Balconies are required to have 30 minutes load bearing capacity (R30). Stairs leading to the extension floor must be constructed of class A2-s1,d0 products and a load bearing capacity of R30 is required. Interior surfaces in apartments can be made from class D-s2,d2 products. The apartment floors have no class requirements for surface material. Interior wall and ceiling surfaces of the fire exits must be made of class A2-s1,d0 products and floors of class D_{FL}-s1 products. The separating walls between fire compartments and staircases must meet EI60 requirements. [6]

If more than one timber based rooftop extension floor is added to the existing P1 class building, then the whole building must be treated with P2 regulations of corresponding building size, including the extension. [7]

The P2 class fire regulations for rooftop extensions are mainly defined by the total floor count of the building. The P2 class fire regulations have different requirements depending on the floor count and building type and use. These are presented in more detail in Appendix 1. All 3-8 floors high P2 class apartment buildings require a sprinkler system. 3-4 stories high apartment buildings are required to have an SFS-5980 standard class 2 - sprinkler system (Finnish translation of the INSTA 900-1:2009 – standard). The single exception is a 3-4 floors high apartment building where all stories belong to the same apartment and the maximum total height of the building is less than 14 meters. [8] Apartment buildings with 5-8 floors require a sprinkler system according to the SFS-EN 12845 -standard OH-class requirements, which require a backup water source and the ability to extinguish a fire.

Conclusions

According to the National Building Code of Finland (2011), it is possible to apply both horizontal and vertical extensions to existing apartment buildings, which enables new options for SmartTES - renovations in Finland. For horizontal extensions the fire regulations depend on how the new extension relates to the existing building. Timber based vertical extensions of apartment buildings are possible up to 8 floors if the total building height does not exceed 26 meters. One single rooftop floor on top of P1 fire class building is the most promising option from the realisation point of view for timber based solutions, as there are no sprinkler requirements. Also multiple additional timber based rooftop floors are possible, but then the whole building must meet the corresponding regulations for P2-class buildings. This practically requires some protective cladding for the load bearing structures and a sprinkler system for the whole building, which might be a feasible solution in case all building systems including water supply systems are renovated.

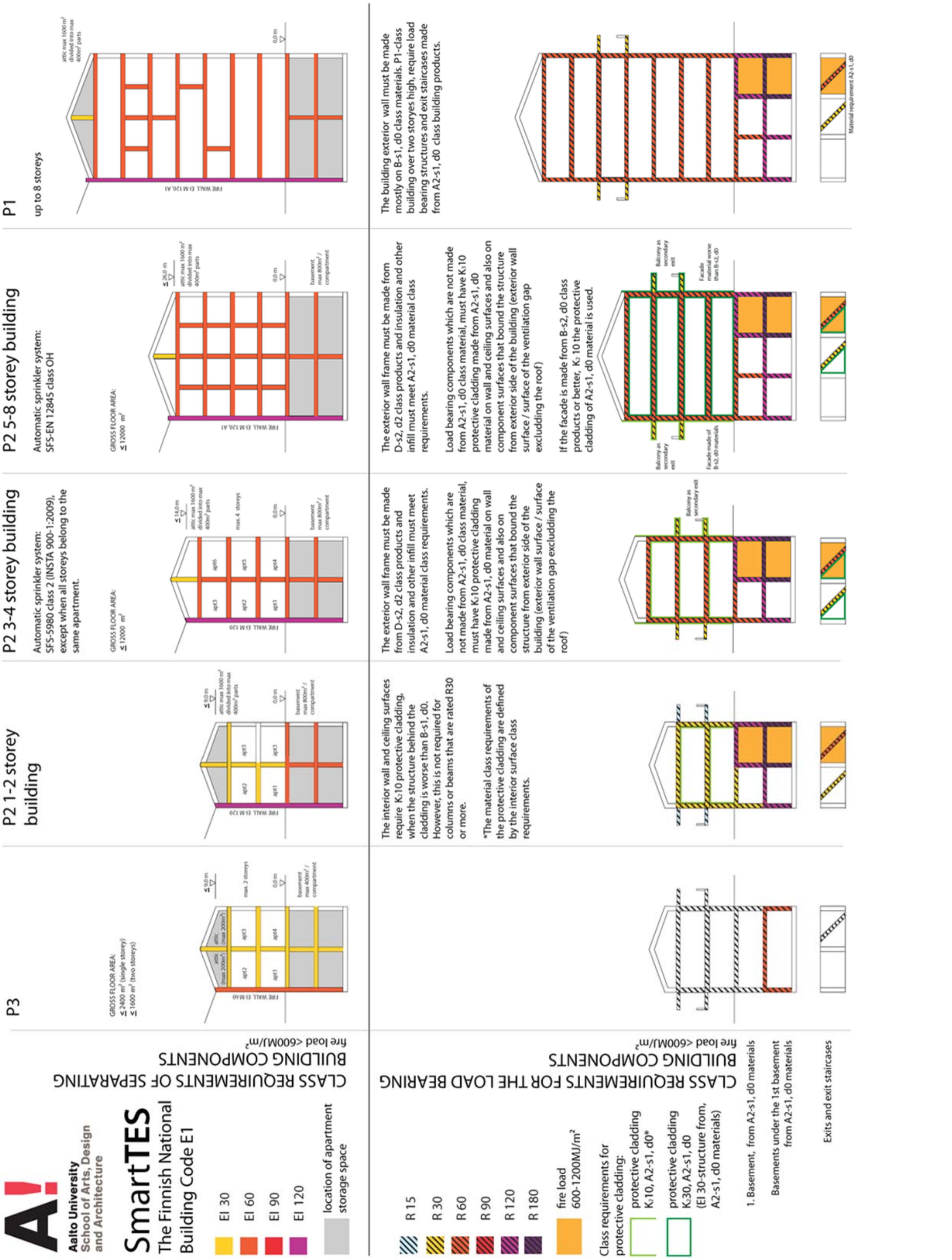
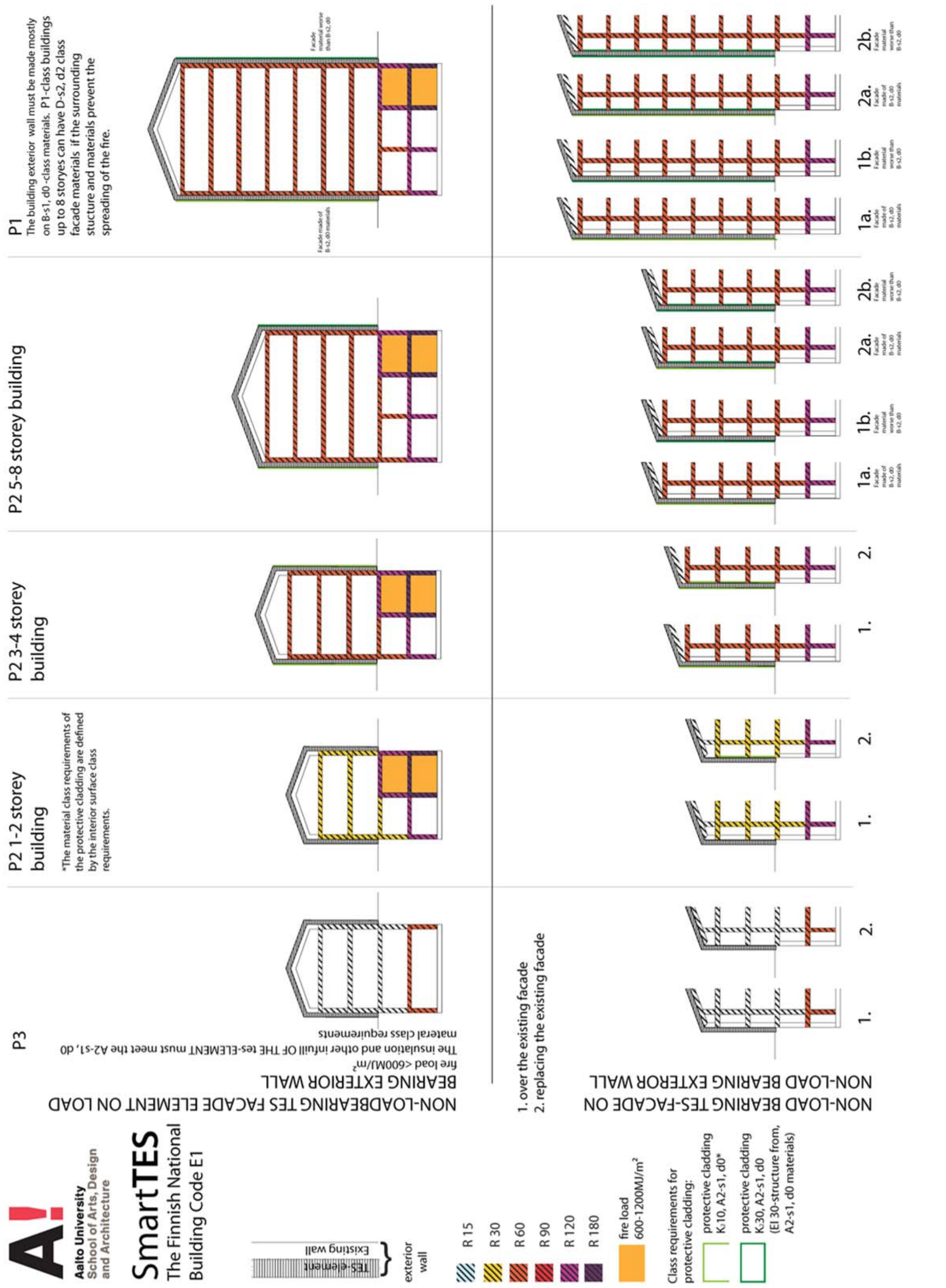


Figure 1 Fire safety requirements Finland – General requirements for load bearing and separating building components.


P3
NON-LOADBEARING TES FACADE ELEMENT ON LOAD BEARING EXTERIOR WALL
fire load <600MJ/m²
The insulation and other infulil OF THE tes-ELEMENT must meet the A2-s1, d0 materal class requirements
P2 1-2 storey building
*The material class requirements of the protective cladding are defined by the interior surface class requirements.
P2 3-4 storey building
P2 5-8 storey building
P1
The building exterior wall must be made mostly on B-s1, d0 -class materials. P1-class buildings up to 8 storyes can have D-s2, d2 class facade materials if the surrounding stucture and materials prevent the spreading of the fire.
1. over the existing facade
2. replacing the existing facade
NON-LOAD BEARING TES-FACADE ON NON-LOAD BEARING EXTEROR WALL
1.
2.
1a.
1b.
2a.
2b.
Aalto University School of Arts, Design and Architecture
SmartTES
The Finnish National Building Code E1
TES-element
Existing wall
exterior wall
R 15
R 30
R 60
R 90
R 120
R 180
fire load 600-1200MJ/m²
Class requirements for protective cladding:
protective cladding K$_1$10, A2-s1, d0*
protective cladding K$_2$30, A2-s1, d0 (EI 30-structure from, A2-s1, d0 materials)

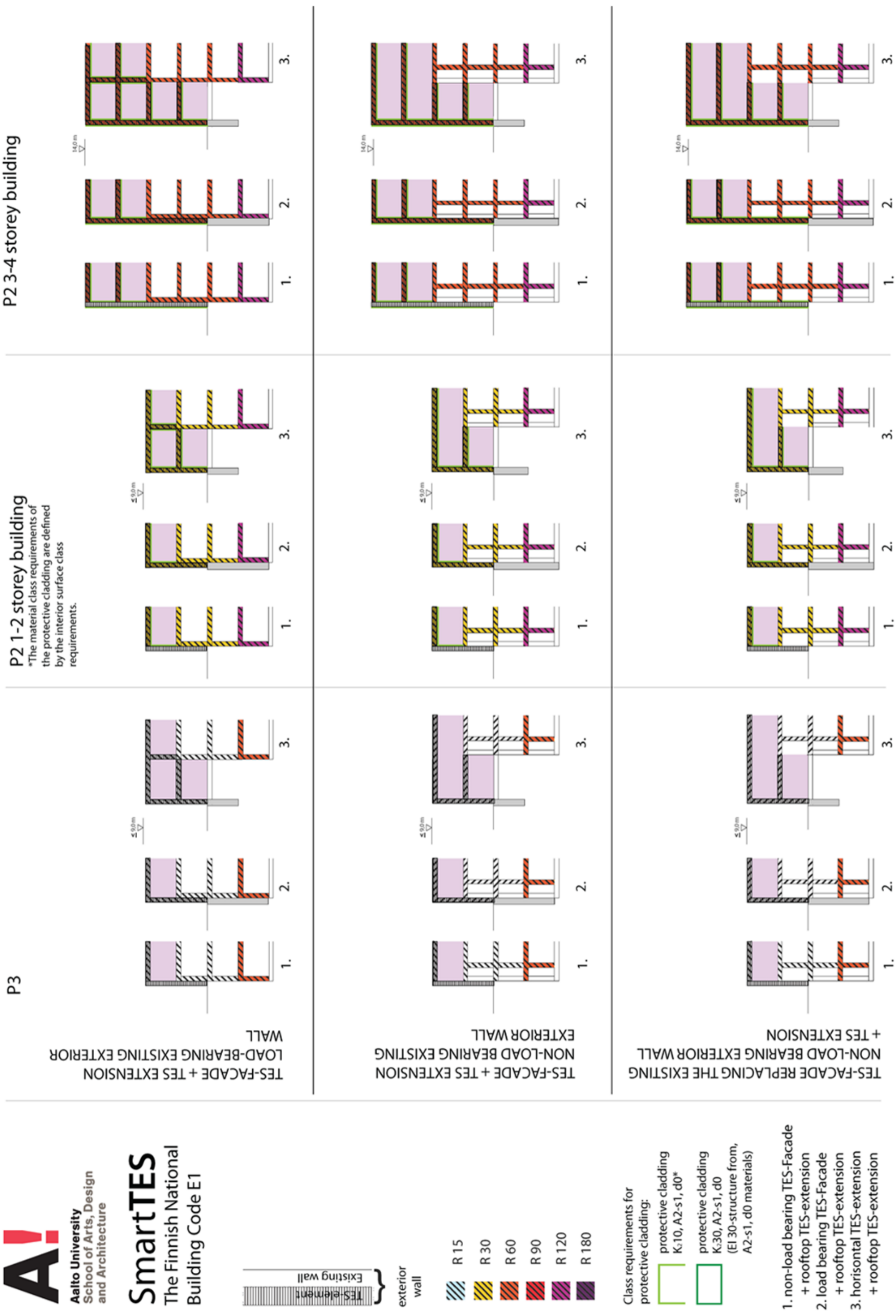


Figure 2 Fire safety requirements Finland – Non load bearing TES facade on load bearing and non-load bearing exterior wall.

Figure 3 Fire safety requirements Finland – TES Facade and TES extension requirements for fire classes P3 and P2 up to 4 floors.

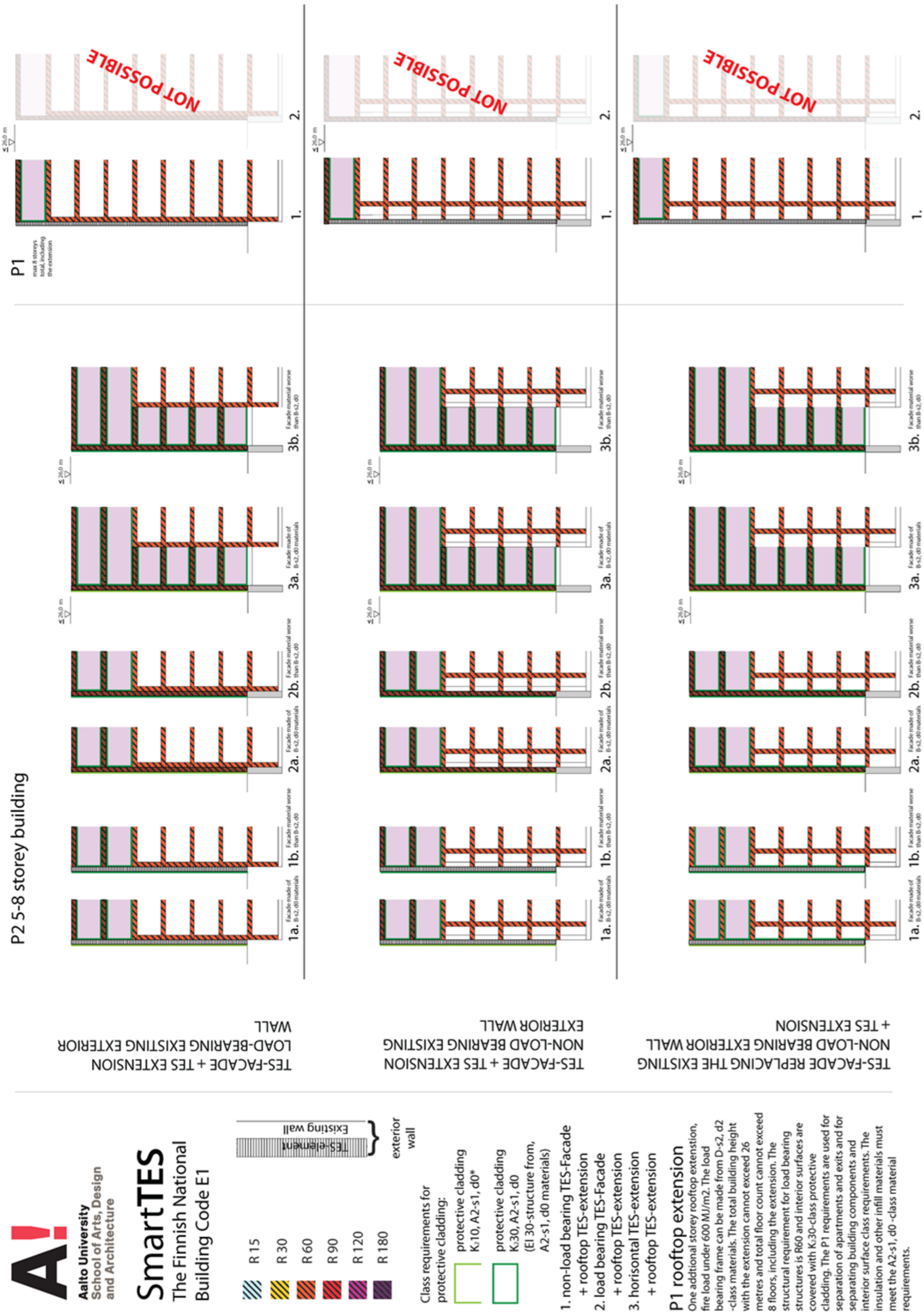


Figure 4 Fire safety requirements Finland – TES Facade and TES extension requirements for fire classes P2 and P1 up to 8 floors.

1.3. Overview Germany

Building regulations
The German overview was compiled on basis of the German Model Building Regulation [10], which serves as guideline for the federal building regulations, and the Model Timber Building Guideline [11]. In Germany each of the sixteen federal states has its own building regulations (Landesbauordnung). Although most of the content of the Model Building Regulation considers those regulations, deviations exist on detail level. However, the overview offers a solid planning basis for the scope of retrofitting measures.

The general fire requirements are
“Buildings and structures must be built, modified and maintained, that the occurrence of fire and the spread of fire and smoke are prevented and in case of fire the rescue of people and animals and effective firefighting are possible.”(§14 in [11])

Building Classes
In Germany, buildings are categorized in five building classes (GK 1-5). The categorization is based on the height of the highest floor level, the size of their units-of-use (Nutzungseinheiten), and the buildings position next to other buildings.

The background for this regulation is that rescue- and firefighting operations strongly depend on the building height. In buildings with low height (maximum floor level height of 7m), building class GK 1-3, a second rescue way can be guaranteed by portable ladders. For higher buildings, building class GK 4 and 5, a turntable ladder is needed and can be applied up to a floor level height of 22 m. Buildings with higher floor levels are therefore classified as high rise buildings. [9]

Besides the floor height the areal expanse of units-of-use have an influence on the rescue operations and therefore on the classification of buildings. A unit-of-use is a closed sequence of habitable rooms, which one or more people use collectively. An essential content in the protection concept of the building regulation is the compartmentation principle, which aims at containing a fire within one unit-of-use for a definite timespan.

TES-Façade – Fire safety requirements
Normally, the old, existing structure already fulfils the fire safety objectives. However, the condition of the existing building has to be verified by a fire safety survey. [1] The TES-element must be build according to valid law and requirements. Thereby the requirements for loadbearing or separating components as well as requirements to the façade cladding must be considered. Independent from the building class a fire spread in and on exterior walls or parts of exterior walls must be limited for a sufficient amount of time. (§28(1) in [11]) Smouldering with in the element must be prevented at any case, as it cannot be controlled by fire fighting. Up to German building class GK 3 combustible materials are allowed and the exterior walls do not have to fulfil any separating functions. Whereas in building classes GK 4 and 5, non-loadbearing exterior walls have to be at least fire-retardant ($E30_{(i\rightarrow o)}$ and $EI30\text{-}ef_{(i\leftarrow o)}$) or in non-combustible materials (Figure 5 No. 1) and cladding of at least class C-s3,d0 is required. The cladding substructure can be in E-d2 (B2), if compensation measures against fire spread are applied. Timber or other normal combustible façade cladding materials need additional approval and special structural solutions such as floor wise separation either by suitable

fire stops or horizontal separating construction. (Figure 5 No. 2) [1][22][23] The component requirements for the floor have to be taken into account, especially if the existing wall is removed. The spread of fire and smoke into the next storey through the TES-Façade and its junction/joint to the floor has to be prevented. If the existing wall is removed, by definition, the TES-joint becomes part of the existing ceiling. (Figure 5 No. 3).

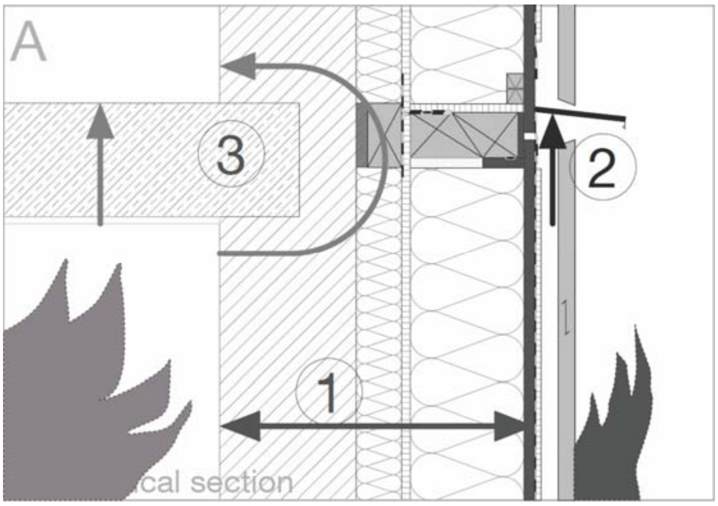


Figure 5: Fire safety detail

TES-Extensions – Fire safety requirements

From fire-safety perspective a TES-Extension differs in two points from the TES-Façade:

- Adding spatial extensions to existing buildings can cause a re-classification into a higher building class, resulting in higher fire safety requirements for all building components.
  - Extending a building vertically: the new height of the highest floor level in respect to the building class has to be taken into account.
  - Extending a building horizontally: the size of the units-of-use and the allowed distance to neighbouring buildings must be taken into account.
- The TES-Element can contribute to the fire resistance of the existing exterior wall, if the fire resistance requirement to the wall was raised in consequence of the building modification
  In TES-Extensions the TES-Façade can be used as a load-bearing wall: For load-bearing (R) walls and floors the separating function (EI) is obligatory. For both criteria, load-bearing and separating function, combined in REI, the same one fire resistance time has to be met. According to [10] the structural application of timber in load-bearing components is limited to building class GK 4 with requirements for the components of REI 60. Additional fire-protection cladding of non-combustible materials ($K_2$60) and non-combustible thermal insulation with a melting point below 1000°C is therefore required. An application of timber-based load-bearing components in building class GK 5 is not allowed at the moment. E.g. while a non-loadbearing exterior wall with separating function in building class GK 4 is required to be E $30_{(i \rightarrow o)}$ EI 30-$ef_{(i \leftarrow o)}$, the same wall containing load-bearing elements is required to have REI 60 $K_2$60 raising the required fire resistance for the separating function considerably, unless the load-bearing components will be built as separate pillars.

Example

Given is an existing residential building with a maximum floor level height of 6.0 m and largest unit-of-use (NE) of 120 m², a pitched roof, free standing, and sufficient distance space to neighbouring buildings. With a maximum floor level height less than 7.0 m and no unit-of-use larger than 400 m² the existing building is classified as building class GK 3 (

Figure 6 Line 2).

Retrofit alternative 1: Energetic retrofit with a TES-Façade

The retrofit measure has no influence on the existing building class. Consequently the TES-Façade has to be planned in building class GK 3, in which there are no component requirements for the TES-Façade as non-loadbearing part of the wall (

Figure 7 Line 2). There is no particular requirement to the façade cladding material (surface) as well (

Figure 6 Line 2).

Retrofit alternative 2: Energetic retrofit with the TES-Façade plus roof-top extension by two floors.

The existing load-bearing walls have the capacity to support the additional load from the roof-top extension or support is added within the building. Therefore the TES-Façade can be applied as non-loadbearing part of an exterior wall. Because of the roof-top extension the maximum floor level height is increased from 6.0 m to 11.6 m and thereby exceeds the limits of building class GK 3. The retrofitted building has to be considered according to building class GK 4 with a maximum allowable floor level height of 13.0 m. This change in building class has extensive consequences for the requirements of components and materials all over the building and not just for the new build parts such as the TES-Façade and the extension as shown in Figure 8 and Table 2:

Component / Material	**GK 3**	**GK 4**
Separating walls in regular and top floor, if habitable rooms above are possible	EI 30	EI 60
Load-bearing walls and columns in regular floor and top floor, if habitable rooms are above possible	REI 30	REI 60
Walls of necessary stair-case rooms in every floor	REI 30	REI 60-M
Ceilings in regular floor	REI 30	REI 60
(parts of) non-loadbearing walls	None (existing)	$E30_{(i\text{->}o)}$ $EI30\text{-}ef_{(o\text{->}i)}$ (with new TES-Façade)
Façade cladding plus substructure.	E-d2	Façade cladding : C-s3, d0 Substructure: C-s3, d0 (B1) or E-d2 (B2) + compensation measures (fire stops)
Roofing (Figure 6 Line 2)	Soft roofing	Hard roofing

Table 2 Change in requirements from build class GK 3 to GK 4 for the given example with *retrofit alternative 2*

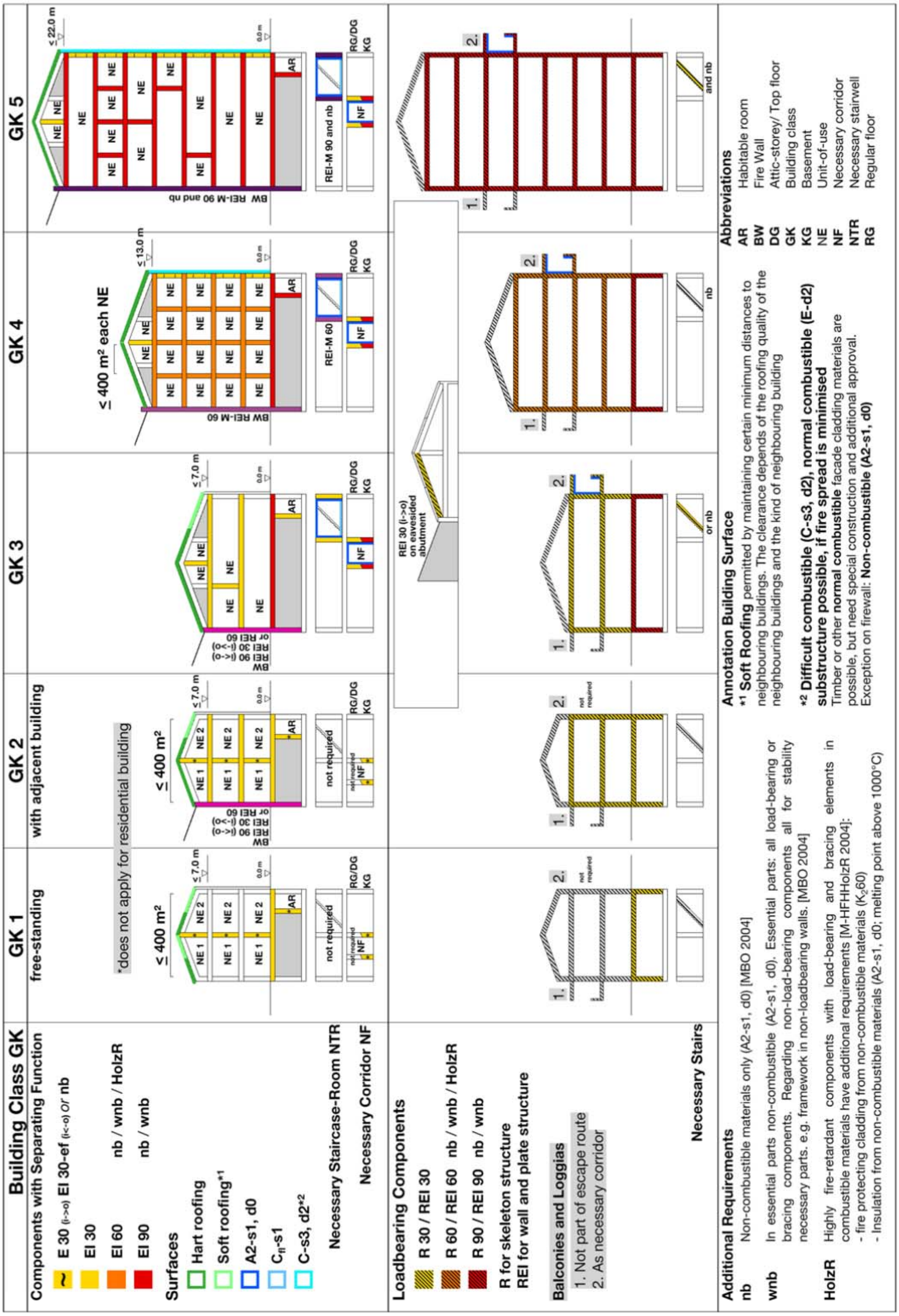


Figure 6 Fire safety requirements Germany – General requirements for load-bearing and separating building components

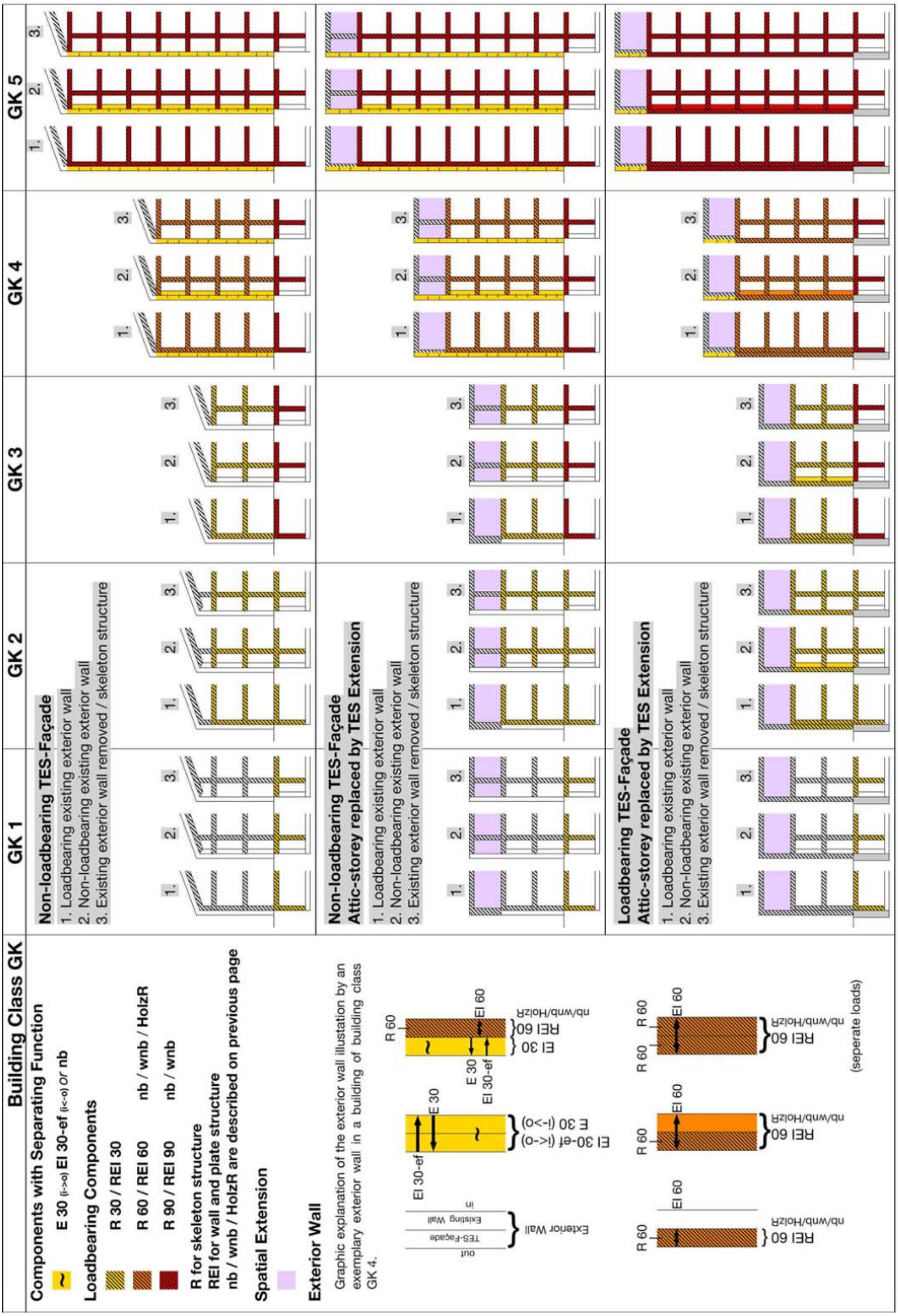


Figure 7 Fire safety requirements Germany – Specific requirements for TES-Façade and TES-Extension (Attic storey replacement)

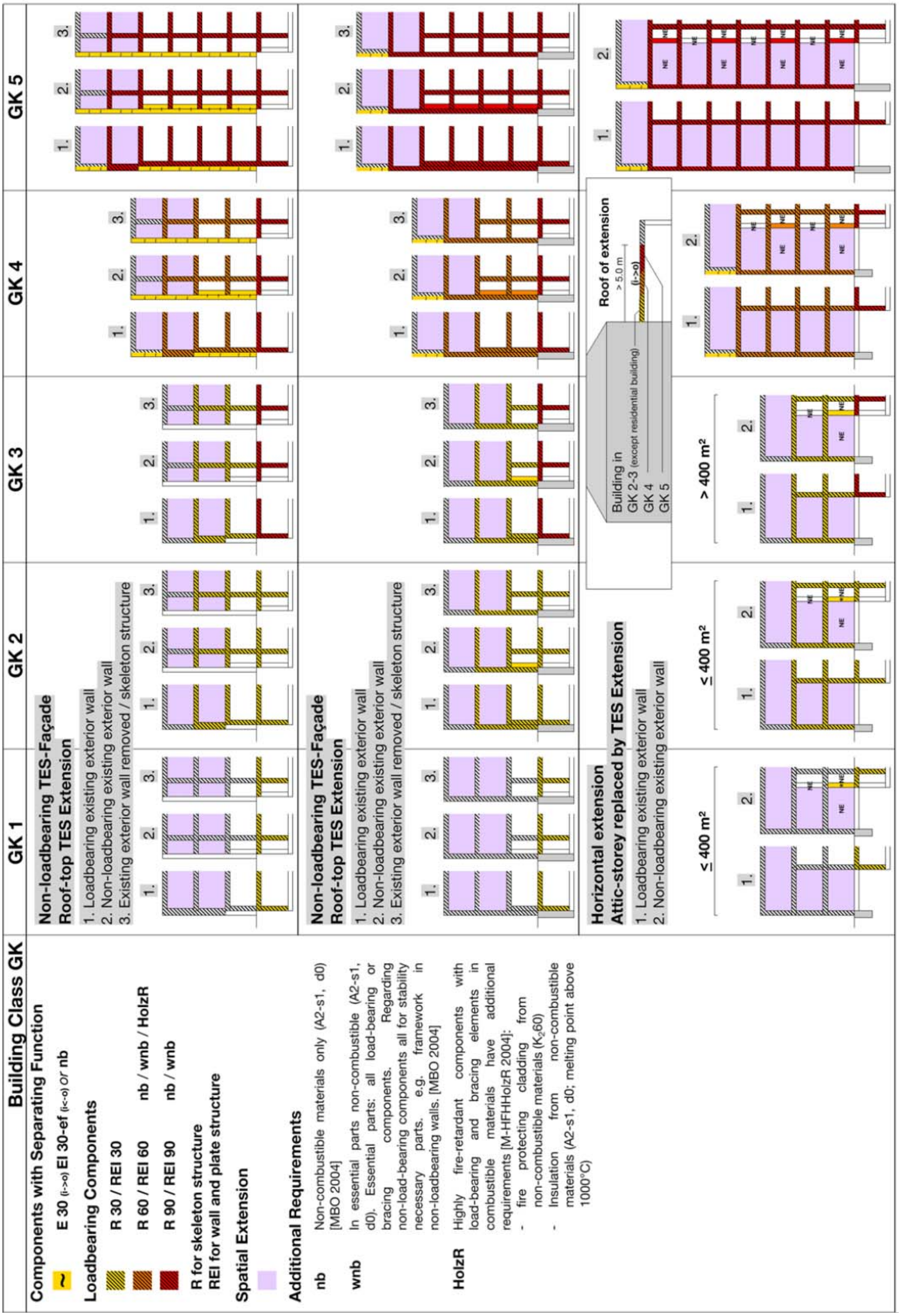


Figure 8 Fire safety requirements Germany – Specific requirements for TES-Façade and TES-Extension (Rooftop and horizontal)

1.4. Overview Norway (Friquin)

Building Regulations

The Norwegian building regulations are presented in the Regulations of technical requirements on building works (Technical Regulations) [31] under the Planning and Building Act [30], 2010, defined by the Ministry of Local Government and Regional Development. A guideline to the Technical Regulations [32] is issued by the National Office of Building Technology and Administration.

The main requirements for fire safety are:
- Buildings shall be designed and built to achieve sufficient fire safety for people in or around the building, for material values, and for environmental and societal values;
- The possibility to rescue people and animals, and for efficient extinguishment of the fire must be sufficient;
- Buildings shall be placed, planned and built such that the risk of spread of fire to other buildings is small. [31]

The fire performances of materials, building components or parts of buildings are not quantified in the Technical Regulations [31], and documentation showing that the chosen fire performance meets the requirements must be provided in each individual project. However, the Guideline to the Technical Regulations [32] describes pre-qualified fire performance for the fire resistance of materials and different parts of the structure (load bearing, separating, fire wall), reaction to fire for surfaces and claddings, height, size and distance between buildings to reduce the risk of spread of fire, fire performance of windows and doors, escape routes, etc. These pre-qualified fire performances do not require further documentation. Figure 9 illustrates pre-qualified performances for load-bearing and separating structures, and the surfaces and claddings in fire compartments and escape routes, in general.

Risk classes and Fire classes (BKL)

In Norway, buildings are categorized in six Risk classes (Risk class 1-6) and four Fire classes (BKL 1-4) [31], see Table 3 and Table 4. The Risk class is based on the threat a fire can have on life and health, while the Fire class is based on the consequences a fire can have for life, health, social interests and the environment. A fire in a building in Risk class 1 and BKL 1 will impose a small threat and have small consequences for life, health, social interests and the environment, and a fire in a building in Risk class 6 and BKL 4 can impose a great threat and have very severe consequences. Buildings are categorized based on their utilization and number of floors, see Table 3 and Table 4.

Buildings where the consequences of a fire can become significantly large for life, health, the environment or society in general are categorized in Fire class BKL 4. Buildings in this class are for example; more than 16 floors high, infrastructure where a fire can damage important social interests, buildings under the ground, buildings with fire load above 400MJ/m², chemical industry, environmentally hostile production, or storage of particularly fire hazardous materials.

The height of the buildings are limited mainly based on the escape, rescue and fire suppression possibilities. In a building with many floors the escape and rescue will take longer time, and access to higher floors will be limited by the available ladder range.

The requirements are explained further in [32], where also several exceptions to the rules are given.

Activity	Risk class
Boat house, Storage, Garage, Shed, etc.	1
Office, Parking house or underground garage, Private cantina, Farm building with animals	2
School, Kinder garden	3
House, Apartment, Fire station with 24h crew, Holiday house, Studio apartment	4
Cinema, Shops and shopping centers, Sports stadium, Museum, etc.	5
Prison, Hospital, Hotel, Care homes for elderly, etc.	6

Table 3 Risk classes Examples [30]

Risk class	Floors			
	1	2	3 or 4	5 or more
1	-	BKL 1	BKL 2	BKL 2
2	BKL 1	BKL 1	BKL 2	BKL 3
3	BKL 1	BKL 1	BKL 2	BKL 3
4	BKL 1	BKL 1	BKL 2	BKL 3
5	BKL 1	BKL 2	BKL 3	BKL 3
6	BKL 1	BKL 2	BKL 2	BKL 3

Table 4 Fire classes (BKL)]

When the Fire class BKL for the building has been defined according to the rules in [31], and the distance to neighbouring buildings are known, pre-qualified fire performances for the load-bearing and separating functions can be found in the Guideline to the Technical Regulations [32]. Pre-qualified fire performances in general are illustrated in Figure 9, and for TES-Façades specifically in Figure 910 and Figure 1011.

Load-bearing function (R) and stability
The main goals of the fire resistance requirements for load-bearing structures are:

- The main load-bearing structure for buildings in Fire class BKL 1 and 2 shall be designed to withstand a fire during the time required to evacuate and rescue people or animals in or on the building.
- The main load-bearing structure for buildings in Fire class BKL 3 and 4 shall be designed to withstand a complete fire scenario.
- Secondary load-bearing structures, structures bearing loads only for one floor and roof structures shall be designed to withstand a fire during the time required to evacuate and rescue people or animals in or on the building. This means that for buildings in Fire class BKL 3 these building parts can have lower load-bearing requirements, R. [31]

The main load-bearing structure for the building stabilizes the building and supports the secondary load-bearing structures. The secondary load-bearing structure are load-bearing structures, floors and roof structures that are not part of or stabilizing the main load-bearing structure. In Fire class BKL 1 and 2 the pre-qualified performances for the main and secondary load-bearing structures are equal, but in Fire class BKL 3 the pre-qualified performances for the secondary load-bearing structures are lower than for the main load-bearing structure, see Figure 9 and Figure 10. [32]

Separating function (EI) and fire compartments
The main goals of the fire resistance requirements for separating structures are:

- Buildings shall be divided into fire compartments in order to separate areas where the risks to life and/or health are different, or the risk of fire is different.

- Fire compartments shall be constructed to prevent the spread of fire and gases to other fire compartments during the time necessary for escape and rescue. [31]

Fire compartmentation shall contribute to safe escape and rescue, and slow down the spread of smoke and flames to reduce the damages to the building. It can also ease the suppression of the fire. The pre-qualified fire performance for separating building components is EI 30 for Fire class BKL 1, EI 60 for BKL 2 and EI 60 A2-s1,d0 for BKL 3.

Pre-qualified fire performances for windows, doors and hatches are also given in [32]. These must have the same fire resistance as the wall they are a part of. Some exceptions are given for windows in opposite external walls or inward corners.

Measures to prevent the spread of fire between buildings
The spread of fire between buildings shall be prevented to ensure the safety of people and animals, and to avoid unacceptable large financial losses or consequences to the society. A crucial factor to the risk of fire spread between buildings is the distance between the buildings. Requirement to a minimum distance of 8.0 m between the buildings is therefore given in [31]. Pre-qualified solutions for buildings with less than 8.0 m distance are given in [32]:

- Buildings lower than 9.0 m, but with distance to neighbour less than 8.0 m must be separated by fire compartmentation walls (EI). Two solutions are possible; either one of the opposite walls has the required fire resistance for fire compartments, or each of the walls has 50% of the required fire resistance.
- Buildings taller than 9.0 m must be placed at least 8.0 m apart, or be separated by fire walls (REI), see Table 5. The fire walls should extend a minimum of 500 mm above the roofing, alternatively the roof construction must have a separating function EI 60 A2-s1,d0.

Fire load (MJ/m²)	**< 400**	**400-600**	**600-800**
Fire resistance	REI 120-M A2-s1,d0	REI 180-M A2-s1,d0	REI 240-M A2-s1,d0

Table 5 Fire walls [30]

The spread of fire from façades up through roof eaves and into attics and roof structures must also be considered, and measures taken to prevent such spread of flames.

Surfaces and claddings
The main goal of the requirements to surfaces and claddings are:

- Materials and products shall not give unacceptable contributions to the fire. Included here is the ignitability, flammability, smoke production, burning droplets, heat release rate and time to fully developed fire. [31]

Pre-qualified fire performances for surfaces and claddings can be found in Figure 9 [32].

External corridors in escape routes
The escape routes shall in a clear and simple way lead to a safe place. It must be sufficiently wide and high, and built as a separate fire compartment. Staircases in escape routes passing several floors shall be separated from other parts of the escape route and other fire compartments.

External corridors shall lead to at least two staircases, and constructed as to ventilate most of the fire gases and smoke that can develop. Pre-qualified fire performances for the surfaces and claddings in escape route corridors and staircases are illustrated in Figure 9. The flooring can be of class D_{fl}-s1, but experience from earlier fires shows that for buildings with more than 2 floors the flooring should be of class A2-s1,d0.

Retrofitting must meet current law

The Planning and Building Act [30] requires that projects on existing buildings shall be designed and built in accordance with the law. On buildings that are not in agreement with more recent versions of the law, or where the utilization is not in agreement with the more recent law, any major renovation, extensions, change of utilization, or significant expansion or change of earlier operations can only be permitted when the changes upgrades the building to meet the provisions in the current law. Therefore, a retrofitting of the façade, a rooftop extension or a horizontal extension might cause a requirement from the local authorities to upgrade a larger part of the building to meet the current law. Current regulations might also categorize the building in a different Fire class than originally.

TES-Façade – Fire safety requirements

There are three different possibilities how to use the TES-Façade elements; replacing the existing exterior wall without removing the old wall (the old wall has no fire safety properties), replacing the existing exterior wall and removing the old wall, or supplementing the existing exterior wall which is load-bearing (and maybe also separating). The TES-Façade elements can have load-bearing and separating functions, or only one of the functions.

When the TES-Façade is installed outside of the existing wall, the separating requirements (EI) for the wall must be fulfilled by the existing wall and the TES-Façade in combination. If the TES-Façade is load-bearing, it must satisfy the load-bearing requirements (R) for the wall. The requirements for external claddings and surfaces in cavities behind must be satisfied by the TES-Façade.

When the existing wall is removed before installing the TES-Façade, the TES-Façade must alone fulfil the requirements for the complete wall, whether it is only load-bearing (R), only separating (EI), or both.

Pre-qualified performances for load-bearing and separating structures, surfaces and claddings for the TES-Façade are presented in Figure 10. Figure 11 illustrates in detail pre-qualified performances for load-bearing (R) and separating functions (EI) for TES-Façades mounted outside of or replacing the existing exterior walls.

The performance given in the figures are pre-qualified by the Norwegian building authorities, but alternative solutions can be used if they are thoroughly documented. As an example; in Fire class BKL 3 structural and separating materials with fire classification A2-s1,d0 according to EN 13501-1 are a pre-qualified performance given by the guidelines for the Technical Regulations. However, if the fire safety of the TES-Façade is documented to satisfy the requirements of the building regulations in individual building projects by testing or calculations, they can also be used in Fire class BKL 3.

TES-Extensions – Fire safety requirements

TES-Extensions can be vertical or horizontal extensions, or attic storey replacements, or a combination of the above. Additions of floors to the building might result in a higher Fire class (BKL) than the building had originally. If this is the case all involved parts of the building must be upgraded to satisfy the requirements for the new Fire class. An attic for storage will have a different Risk class than an apartment, for example. The attic can therefore be categorized in a lower Fire class and have lower requirements than the floors below. If the attic is converted to an apartment later, the Risk class and Fire class will change for that floor. In the case of adding one floor to the building this might in many cases result in a higher Fire classification for the entire building, and requirements for better fire performance for walls, floors and roof.

The walls and roof structure in a Rooftop extension or Attic storey replacement must meet the same requirements as the cases where the TES-Façade element replaces or supplements the existing external wall. A horizontal extension will compare to the cases where the existing exterior wall is removed and replaced with TES-Façade elements.

Conclusions

The TES-Façade must fulfil the fire safety requirements in [31] alone or in conjunction with the existing wall. The fire performance must be equal to the pre-qualified fire performances given in the Guideline to the Technical Regulations [32] or better.

Retrofitting of a building, Rooftop extensions, horizontal extensions or Attic storey replacements might bring the building, or part of the building, into another Fire class BKL than it was originally, which in turn can result in a requirement to increase the fire performance of the building.

Where a new floor is built on top of the building as part of the load-bearing TES-Façade or TES-Extension system, the structures for the new top floor can be considered as a secondary load-bearing structure, see Figure 10.

The TES-Façades and TES-Extensions with walls, floors and roofs with fire resistance (R)EI 30 or (R)EI 60 can be used in Fire class BKL 1 and 2, respectively. Because the TES-Façade and -Extensions contain combustible materials, e.g. timber, and therefore cannot be classified (R)EI xx A2-s1,d0, they cannot be used in Fire class BKL 3 without further documentation to prove compliance with the Technical Regulations [31].

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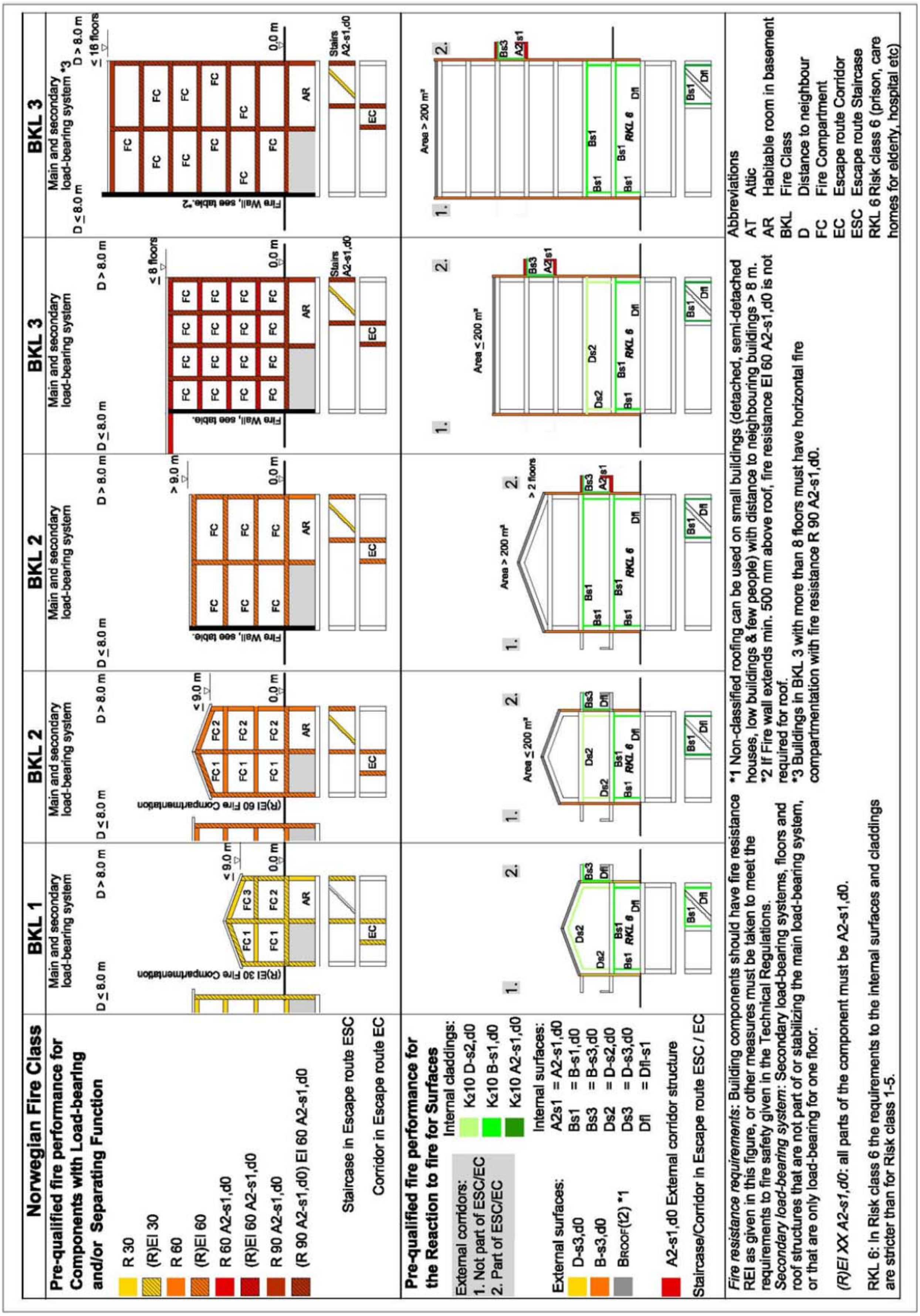


Figure 9: Fire safety requirements Norway – General requirements for load-bearing and separating building components, and surfaces and claddings.

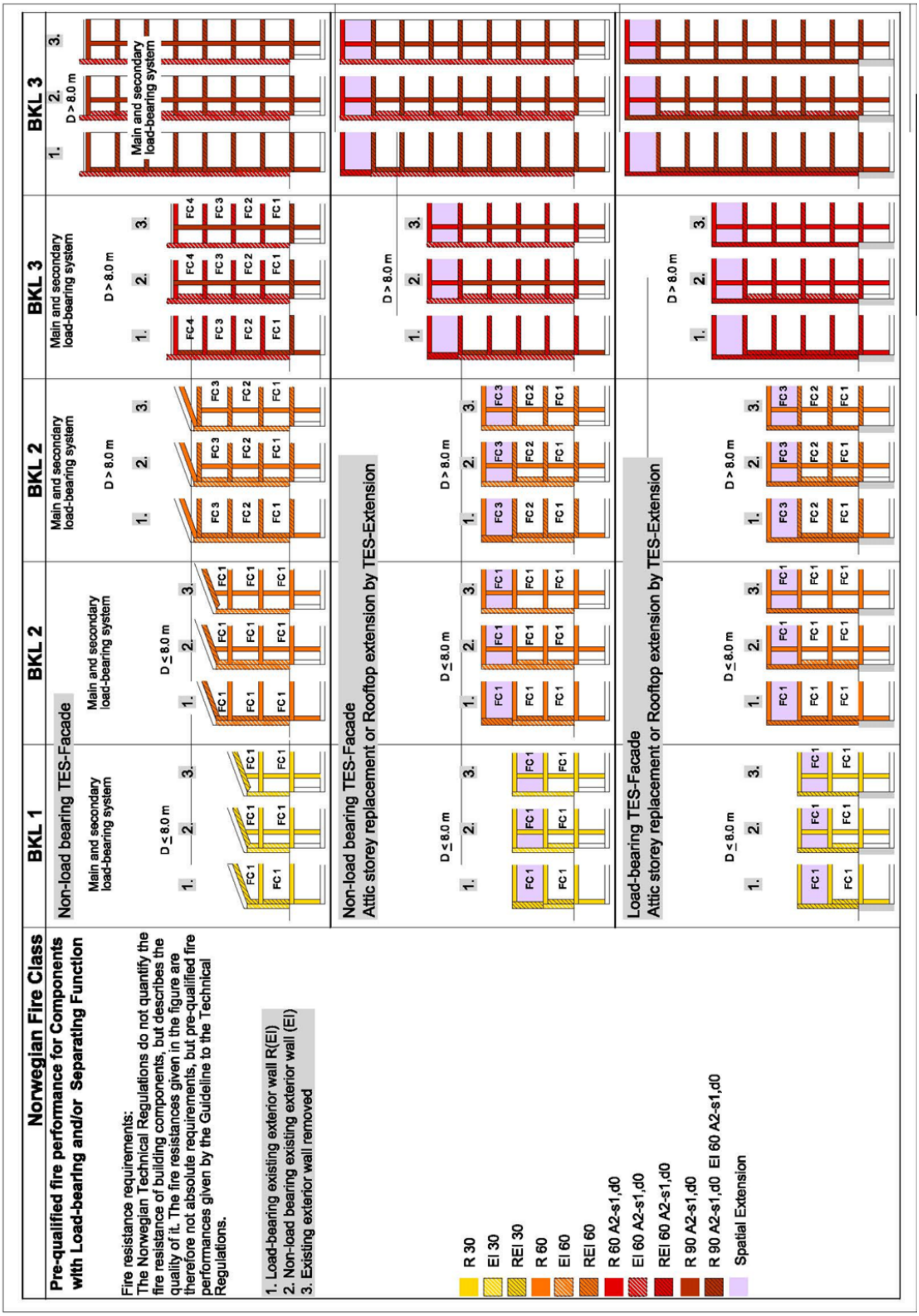


Figure 10: Fire safety requirements Norway – Specific requirements for TES-Façades and TES-Extensions

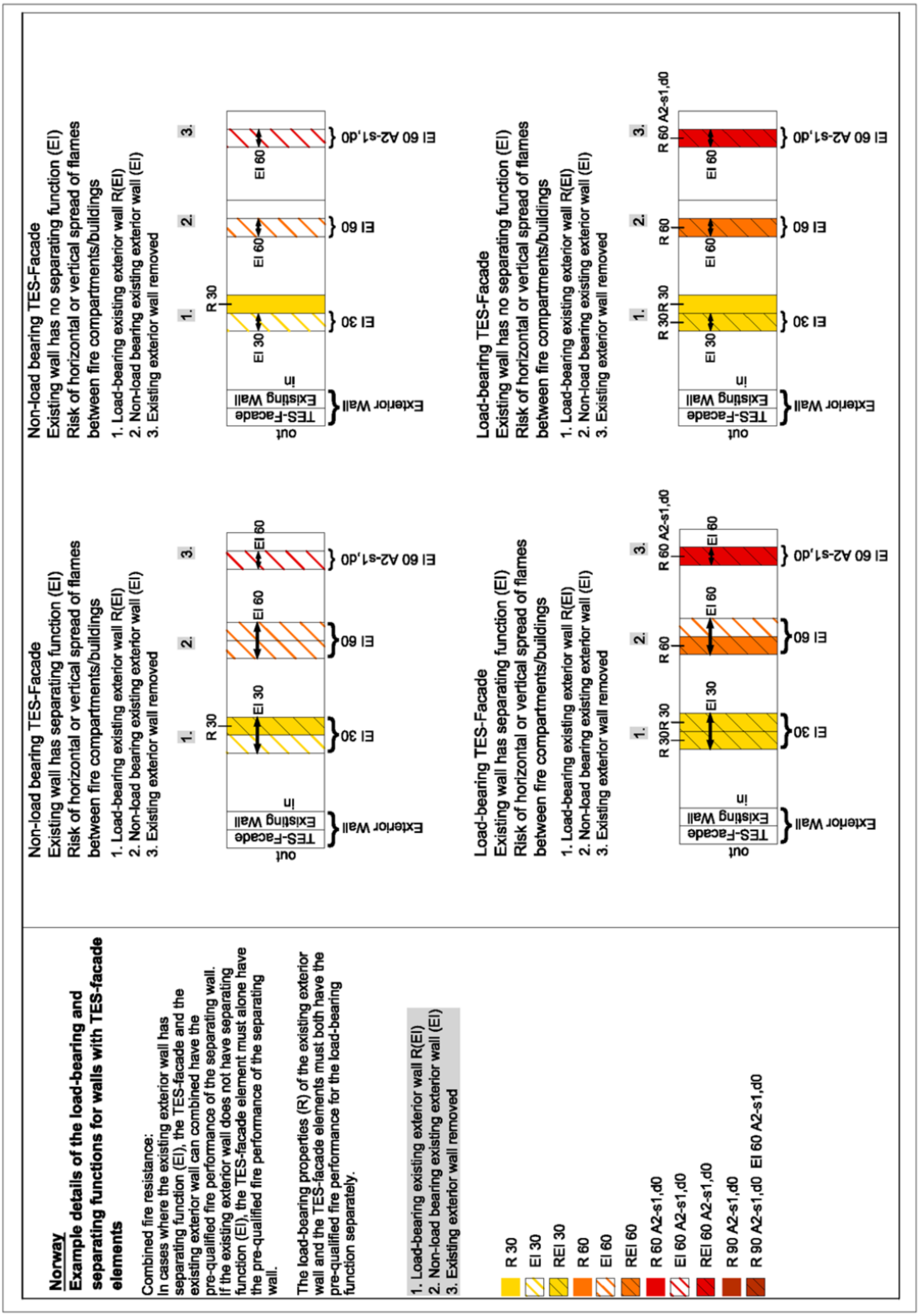


Figure 11: Fire safety requirements Norway – Specific requirements for TES-Façades in detail.

2. Construction detail in the context of fire safety

2.1. Fire safety objectives specified for the TES-Façade

According to the principals stated in the interpretative document of the European Communities to the ‘safety in case of fire’ [34] the fire safety objectives for the TES-Façade are specified:

1. Occupants shall be able to leave the building or be rescued
   - Keeping the escape routes free (no falling off of large parts of façade and protection from such through canopies above exit doors)
   - Limited smoke generation and smoke propagation;
   - No spread of fire through the façade and wall elements into the building. Cavities where flames can spread undetected should be avoided.

2. The safety of rescue teams shall be taken into account
   - No heavy and large falling off parts;
   - Extinguishing the fire in all parts of the façade-system must be possible;
   - Limited smoke generation enabling visibility, fire-fighting and rescue operation.

3. Load-bearing and separating structures and elements shall resist fire for the required minimum duration of time
   - Assure for existing wall or TES-Façade element and anchorage of the TES-Façade element;
   - Stability of the TES-Façade itself, even if no external loads are carried (see 1.).

4. The generation and spread of fire and smoke on the façade shall be limited, as well as the propagation into the building and to neighbour buildings
   - Applying structural fire-stops, façade sprinkler systems, window fire curtains, and fireproof glazing;
   - Fireproof connections and joints;
   - Preventing the chimney effect by avoiding cavities in the façade where flames and smoke can spread;
   - Keeping safety distances or applying building material with low flammability,
   - Organizational measurements, e.g. not placing waste-cans close to the building;

2.2. Fire scenarios

Several fires in the last decades showed that occurrence of an external wall or façade fire may be attributed to one of the following three scenarios.

- ignition of the façade by radiation from an adjacent building fire or by flying brands,
- external exposure and ignition by e.g., burning of waste container or car fires close to the façade,
- ignition of the façade by external flaming out of a window in a post flash over compartment fire

Due to the amount of available fuel in buildings with office or residential occupancy ($q_{f,k}$ (80) = 511 – 948 MJ/m² [16]), the latter scenario generally represents the most critical condition to the façade, with hottest temperatures and longest duration of fire exposure. In ventilation controlled fires spilling flames out of a broken window with length of up to 4 m may occur. [20][21]

To ensure an appropriate level of safety without any negative influences of the TES-façade elements four scenarios / fire spread paths have been identified and investigated, as shown in Figure 12:

(1) separating function of the façade element itself and contribution to the fire resistance of the existing wall respectively
(2) fire penetration into the TES-Element and uncontrolled propagation inside the structure, exclusion of smouldering fires
(3) uncontrolled fire spread onto the façade and at the rear ventilation gap
(4) spread of flames, hot gases and smoke through the junctions of wall/TES element – floor

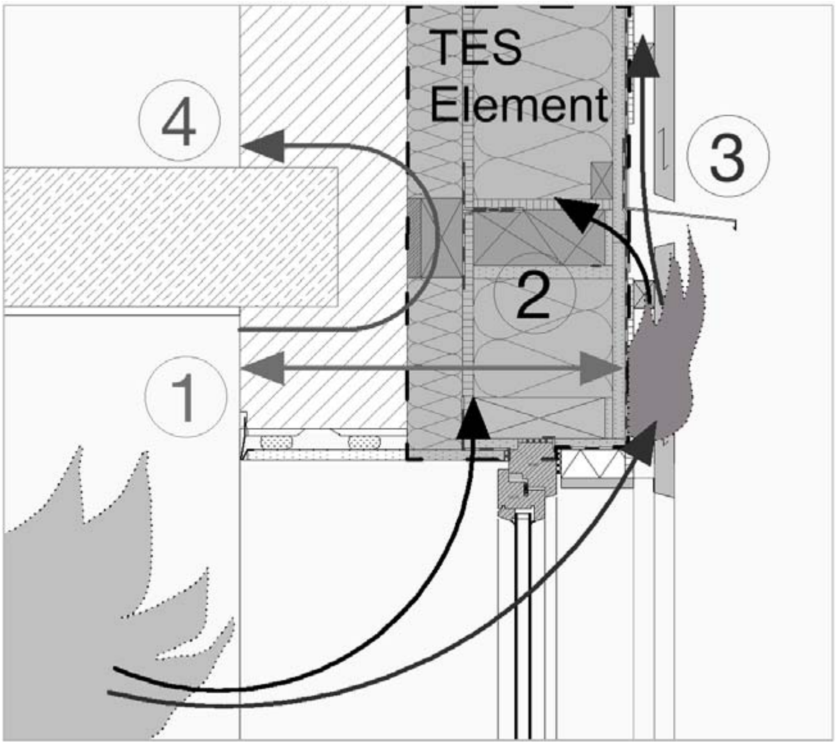


Figure 12 Fire protection objectives

In this project no further examinations towards the separating function of a TES-Façade as part of an exterior wall have been conducted. Together with the existing wall this criterion is usually met, approved wall assemblies exist from various producers, or assemblies can be calculated according to the Eurocode [16].

The main constructive measure is the encasing of the element with a non-combustible cladding. The design and verification of the encasing layer is part of the following examinations. Besides the encasing quality the fire safety of the system depends on the sensibility of the timber and thermal insulation behind. An advantage of the TES-Façade is the flexible application of thermal insulation material. The system bears the potential to make eco-friendly but combustible thermal insulation and structural materials feasible for the application in multi storey buildings.

2.3. Design process for fire safety

The further investigations described herein are intended to determine the fire behaviour of the TES façade element (and façade cladding), exposed to heat and

spilling flames of a fully developed ventilation controlled compartment fire, with excessive fuel burning outside the window.
Thus, in terms of thermal exposure the soffit area around the window opening is the most critical to the TES-façade. However, for this application the severity of exposure is not defined in general, by a European standard or testing regime and therefore in focus of the further investigation.

Assessment of fire severity and determination of a design fire
Based on fire tests [23][39] and calculation methods, such as presented in standards or literature [17][20], it is well known, that the temperature and heat flux along the façade decreases rapidly with increasing height above the window, due to the entrainment of ambient air. Structural members located outside of a burning compartment can be designed and tested for fire resistance with the external fire curve [17], unless they are engulfed in flames.
The exposed area around the window opening (soffit and upper parts of the reveals) is fully engulfed in flames, whereby the temperatures may assumed close to those inside the compartment [23][39]. The lower exposure in early stages of the fire, the reduced re-radiation of the compartment and the starting mixture of hot gases and fresh air in the post flash over phase only have a minor impact to the temperatures at the soffit and will be neglected in following calculation.
Based on the calculation method presented in Annex A and B of EN 1991-1-2 and the Zone model O-Zone [40] a parametrical study has been conducted to determine the temperatures inside the compartment and for the window soffit. The study considered the effects which various model parameters (opening factor, fuel load density, material of envelop, fire growth rate) may have on the temperatures in the compartment. Maximum opening factors for a ventilation controlled fire, fast and medium fire growth rates and fuel load density of office and residential buildings have been used to achieve high temperatures in the early phase of the fire. The maximum temperature in the derived design fire of TES façade elements is reached at the time when the fire services starts intervention, which for Germany can be assumed to be after 20 minutes fire exposure.

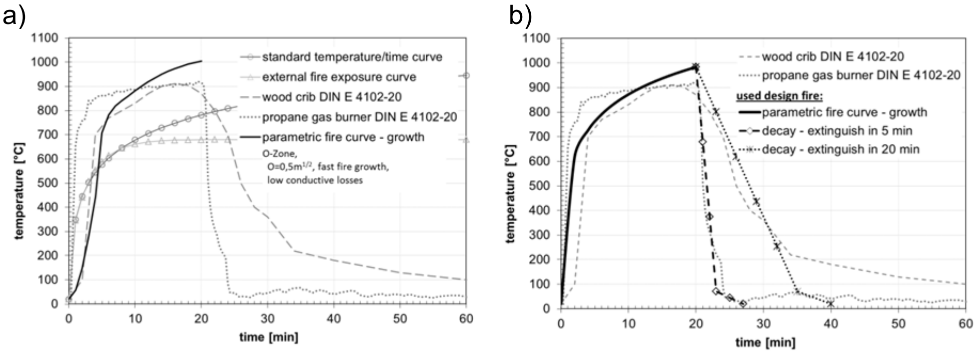


Figure 13 Derived temperatures for the soffit and comparison to full scale test result and standards a) comparison of temperature time curves, b) used temperature time curve (design fire) in FE simulation

As shown in Figure 13a) the exemplified parametric temperature time curve (black solid line) in the growth phase of a fire correspond well with soffit temperatures measured in full scale façade fire tests with a wood crib as fuel (dashed line) and for a propane gas burner fire (dotted line) respectively [22]. For comparison the external fire exposure curve (solid line with triangle marks) and the standard temperature/time curve of EN 1991-1-2 (solid line with circles) are depicted as well, which are commonly applied for most component tests regarding load-bearing and separating function.
The decay phase of the exposure is strongly influenced by the method and severity of fire service intervention. For further numerical simulation and design of the TES façade elements the duration of the decay phase was estimated conservatively to be the same as for the growth phase of the fire.

Hence, after reaching the peak temperature, the curve declines to 20°C as a bi-linear function in 20 minutes and 5 minutes time respectively, as depicted in Figure 13b).

FE-Simulation
As described before the thermal exposure level for the window opening was derived from fire tests, fire engineering methods and under consideration of fire service callout time.
In further the pre-design - and detailing process of the façade elements numerical simulation (FE) were conducted to determine the appropriate dimension of the external lining.
In the simulations with the finite element software package Ansys [35] the entire external surface of the specimen was exposed to the derived fire curve of Figure 3b). The applied thermal exposure consisted of a radiative and convective fraction. As suggested in EN 1991-1-2, the emissivity ε and convection coefficient α_c at exposed side were assumed equal to 0,8 and 35 W/m²K, respectively. Material properties for timber, thermal insulation and gypsum fibre board were taken from EN 1991-1-2 and literature [36][37] and implemented in the transient simulation.
The temperatures inside the specimen were measured at several points to assess critical condition in the growth and decay phase of the fire exposure.

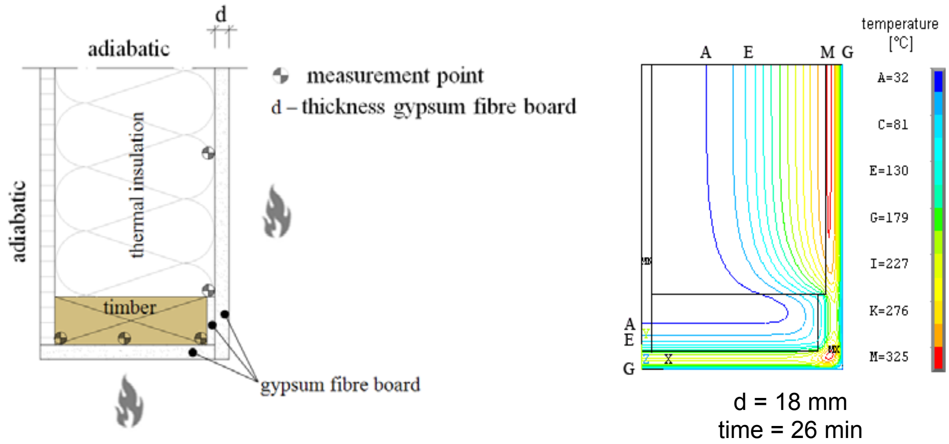


Figure 14 Modelling setup and isotherms at the time of 26 minutes

The results of the simulation suggest a gypsum fibre board thickness of 15 to 18 mm, to avoid an exceeding of critical temperatures of 200°C for combustible thermal insulation and 300°C for timber respectively [38].

Real fire experiments
In the real fire tests the evaluations of exposure and preliminary FE-simulation were to be verified and adjusted. In comparison with existing test setups the behaviour of the encasing cladding as main constructive measure against fire penetration was examined. Besides the encasing quality the tests gave an impression of the sensitiveness and behaviour of timber and thermal insulation protected by the encasing cladding. Furthermore the protection capacity of joints in the encasing cladding at window lintel and at the junctions of elements was evaluated. On the basis of the evaluations of fire severity, preliminary FE-simulation, and relevant building materials the design of orientating small-scale fire tests was derived. From the small-scale test results and improved pilot project construction details the full-scale fire test was assembled and performed according to DIN E 4102-20.

2.4. Window-opening – Small-scale tests

Test setup

This orientating test series resembles fire out of a window opening. To test the area above and next to the window a furnace as given **Fehler! Verweisquelle konnte nicht gefunden werden.** was chosen as test stand. The specimen placed inside, is separated in a left and right side, offering two configurations per test. By coupling the diesel burner with thermal sensors the temperature in the furnace can be applied according to the parametric temperature curve as given in Figure 13. All specimens were exposed to that parametric temperature curve for 20 minutes followed by a cool down phase, in which fresh air was blown into the furnace (necessary to protect the diesel burner). Afterwards the specimen was lifted out of the furnace and extinguished with spraying water onto the surface. The further observation, with regards to smouldering fires inside the specimen took another 15 hours.

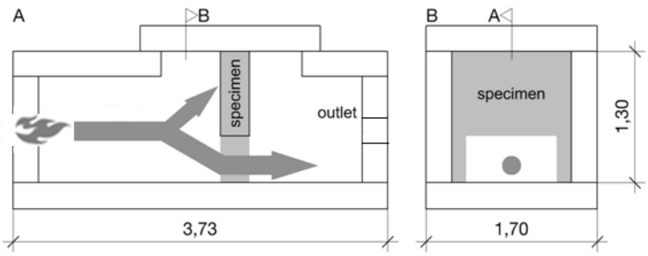


Figure 15 Furnace section – area of window opening

Tested construction parameters

Eight different construction designs (Table 6) were assessed with respect to the protection capacity of encasing cladding, the occurrence of critical temperatures, the fire spread inside the elements and smouldering fires. Beside the spatial undisturbed area information on the influence of joints, junctions and fasteners were also gained.

(a) Stone Wool (b) Wood Fibre (c) Loose Wood Fibre (d) Cellulose Fibre

Figure 15 Thermal insulation materials

Different combustible timber-based thermal insulation materials were compared to each other and to non-combustible stone wool. The loose wood fibre and the cellulose fibre insulation were blown-in materials. As the ignition behaviour of the combustible thermal insulation materials varies, both the 15 mm and 18 mm thick gypsum fibre boards were considered as encasing cladding. Additionally two different wood-fibre-based ETICS (External Thermal Insulation Composite Systems) were tested. Another assessed parameter was the jointing detail of the window frame to the TES-element and the issue, if there is a difference between a continuous encasing cladding (see Figure 16, no. 1-4) and one that is separated by a combustible timber window frame.

Test series	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Thermal insulation in-fill	Cell. fibre 1	Cell. fibre 2	Loose wood fibre		Mineral wool	Wood fibre		
OSB	15 mm							
Thermal insulation adaption layer	Cellulose fibre 1		Mineral wool					
Timber frame	60x200 mm²							
Encasing cladding (gypsum fibre board)	15 mm	15 mm	15 mm	18 mm	15 mm	18 mm	10 mm (front only)	10 mm (front only)
ETICS	-						ETICS 1 (Wood fibre)	ETICS 2 (Wood fibre)
Continuous or separate encasing in reveal and soffit area	Continuous				Separate			

Table 6 Small scale fire tests - Relevant construction parameters

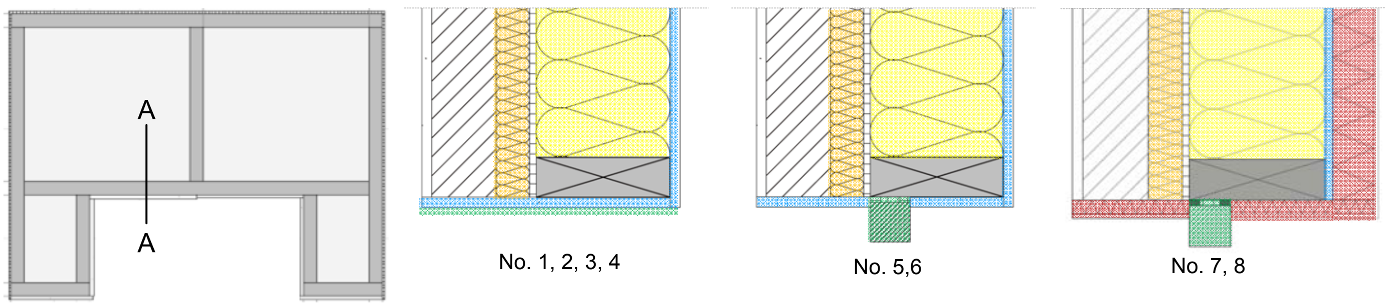


Figure 16 Test specimen and variants in section A-A (Colouring and number according to Table 6)

Test results

Plain encasing cladding with gypsum fibre boards (No. 1-6 in Table 6*)*

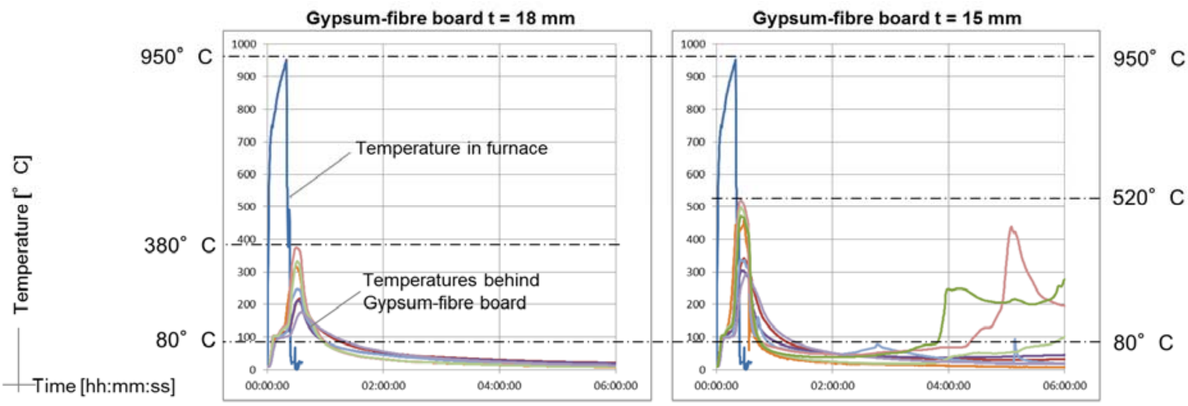


Figure 17 Time-temperature curve showing temperature rise behind the plain encasing gypsum-fibre boards for 18 mm (left) and 15 mm (right) thickness.

During the fire-impingement neither the 15 mm gypsum fibre board nor the 18 mm gypsum fibre board showed any relevant cracks in their surface. The temperature behind the 18 mm gypsum fibre board stayed below 150°C, while the temperature behind the 15 mm gypsum fibre board exceeded 350°C in the area of cavity insulation. Temperatures around 350°C for a short period of time were acceptable for the cellulose fibre; if the oxygen supply was kept low. At the end of the fire impingement the temperature behind the 18 mm gypsum fibre board was significantly lower than behind the 15 mm gypsum fibre board (up to 200 K). In the cooling phase the quick drop in temperature caused both types of gypsum fibre boards to crack. Some cracks were as wide as 12 mm. The cracks in the 18 mm gypsum fibre board were less permeable than those in the 15 mm gypsum fibre board, hence.

(a) in the furnace (b) after cooling phase (c) during observation

Figure 18 Crack development in gypsum fibre board (15mm)

In the reveal and soffit area (except the lintel-corner) the temperature for the timber members did not rise above 350°C behind the 15 mm thick gypsum fibre board and not above 150°C behind the 18 mm thick gypsum fibre board. At the lintel-corner several penetrations of fire through butt jointed gypsum fibre boards were observed.

(a) 15 mm (b) 18 mm

Figure 19 Charred timber behind the 15 and 18 mm gypsum fibre boards in the reveal

The applied butt-joint between the gypsum fibre boards in the soffit/lintel was insufficient. So the constant supply with oxygen by cracks in the 15 mm gypsum fibre boards and opened joints in the soffit/lintel area, promoted by gaps in the thermal insulation, caused a chimney-effect and kept a smouldering fire alive.

(a) Loose wood fibre (b) Cellulose fibre

Figure 20 Smouldering of fibre thermal insulation material

The products of wood- and cellulose fibres were all vulnerable to smouldering fires. A precise filling, a reduced temperature impact, and the prevention of the chimney-effect can decrease this vulnerability. Contrary to the previous results the cellulose-filled specimen with an encasing cladding of 18 mm gypsum fibre board performed well. In all readings of the thermocouples the temperature declined from 350°C to

50°C while observing. A direct ignition of the equalizing-layer filled with mineral wool or cellulose through the soffit was not detected. As conclusion of the small-scale tests follows, that the applied exposure can cause fire spread inside the elements which is difficult to detect and to extinguish. Main reasons are an insufficient dimension of the encasing cladding, detailing of the joints, gaps and void cavities. Comparing the temperatures in the specimen, the results of the FE-Simulation have partly been proven. As a consequence of the results for the further tests an 18 mm thick gypsum fibre board was recommended. To prevent fire penetration through the joints in the soffit/lintel area each gypsum fibre board-joint has to be back-blocked with an extra layer of gypsum board, especially in the thermal highly-exposed lintel-corner.

Figure 21 Small-scale fire test with loose wood fibre and gypsum fibre boards in 18 mm (left) and 15 mm (right) after 15 hours of observation

External thermal insulation composite system (ETICS) (No. 7, 8 in Table 6*)*
Both systems of the specimen were penetrated by fire within the 20 minutes of fire impingement. During the further observation a combination of smouldering fire and visible burning within the ETICS overcame the rear 10 mm thick gypsum fibre board and ignited the wood-fibre insulation in the TES-element. In spite of heavy watering the ETICS a continuous re-ignition occurred. As a conclusion of those results wood-fibre boards cannot be recommended for an ETICS applied on a TES-element with fire safety requirements in higher building classes.

For extended information about these tests, see [25].

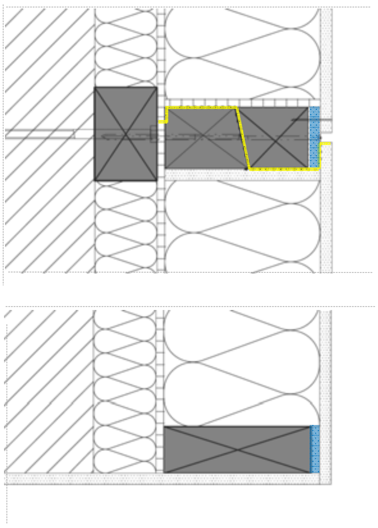
2.5. Large-scale real fire test

Test construction parameters
Based on the results of the small-scale fire test for the window opening, the construction of the large-scale test was determined. The assembly corresponds to small scale fire test Table 6 No. 2.
The adaption layer around the window is filled with non-combustible material (mineral wool) to prevent an ignition within the layer. Due to constructional advantages cellulose fibre is blown into other parts of the layer and used as infill thermal insulation.
As a result of the small-scale tests the gypsum fibre board was dimensioned with 18 mm thickness. Element joint areas and front lintel corners were reinforced by an additional stripe of gypsum fibre board (see Figure 22).
No façade cladding was applied. Particular tests for combustible façade claddings were conducted in [22]. In chapter 2.6 a combination of the current results with the results from [20] is suggested.

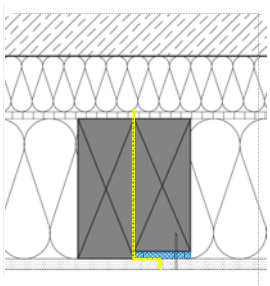
Test series	No. 1
Thermal insulation in-fill	Cellulose fibre 2
Thermal insulation adaption layer	Cellulose fibre 2 / mineral wool in window area
Encasing cladding (gypsum fibre board)	18 mm
Jointing of encasing cladding	Deposit of 10 mm thick stripe gypsum fibre board
Façade cladding	-
Continuous or separate encasing cladding in reveal and soffit area	Continuous

Table 7 Large scale fire tests - Relevant construction parameters

The TES-Façade is produced in a high prefabrication level often with a fully mounted façade cladding. Therefore the encasing cladding behind is hardly reachable for further onsite work. Furthermore the gap in the element joint zone can barely be closed by applying conventional gypsum board gluing. Therefore the joint of two elements was backed by an additional stripe of gypsum fibre board (see Figure 22). The same method was used at the lintel corner, to create a step joint, as a consequence from fire penetration in the small-scale tests.



(a1) Vertical section



(a2) Horizontal section

(b) Specimen element piece

Figure 22 Element joint and window sill

Test procedure

The test approach corresponds to DIN E 4102-20 [14] "special proof for the fire performance of external walls" as part of a draft standard of the German Institute for Building Technology. The test set-up is an outside wall in full- scale with a nook / inward corner, on which the façade system specimen is mounted in its original state (see Figure 23). A gas burner exposes the specimen thermally under natural ventilated conditions. As defined for flame retardant façade systems/materials, the exposure time is 20 minutes [26].

(a) Testing setup (b) While testing (c) After the test

Figure 23 Exterior wall test setup

Test results

Over the 20 minutes time of fire exposure and beyond no damage like cracks in the gypsum fibre board surface were observed. After shutdown of the gas burner and in the following observation phase of roughly 20 hours no smouldering fire or visible burning occurred. The quick cooling of the specimen surface through watering with a spray jet from a fire hose immediately after the shutdown of the gas burner did not cause any recognizable damage like, cracking of the gypsum fibre boards that occurred in the small-scale fire tests.

Parts of the gypsum fibre board were removed and the elements dismantled. Damages caused by the flames were not observed on the timber elements or on the thermal insulation material in the elements and the adaption layer.

Observations	Moment of occurrence [testing minute]	Time span [minutes]	Max. expansion from firing chamber lintel [m]
ignition of façade parts	none		
cracks or flaking	none		
flaming droplets or debris	none		
fire in thermal insulation	none		
smouldering	none		
maximum flame length	4	15	2.3 m
smoke emission	little over entire testing and observation time		
anomalies	none		

Table 8 Test results (20 minutes testing + 60 minutes observation)

For extended information to this test, see [26][25]

2.6. Applying a wooden cladding to the TES-Façade

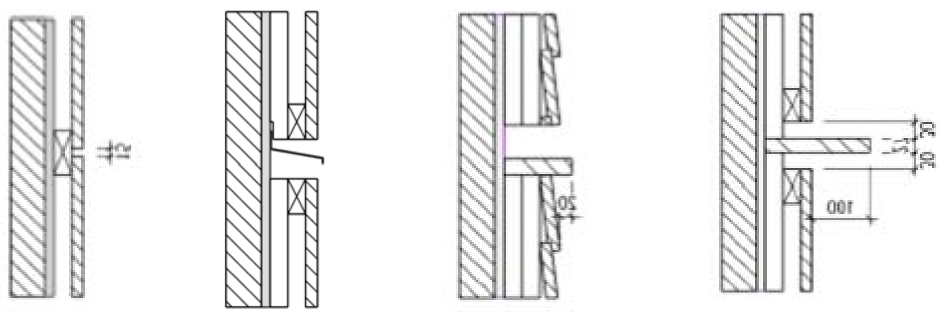


Figure 24 Exemplary wooden façade cladding assemblies with fire stops that were examined in [22]

For the application of combustible claddings research and testing was conducted in [22]. Twenty-eight different wooden façade claddings varying in fire stops, façade material und substructure were tested in a large-scale fire test setup on a non-combustible wall surface – similar to the conducted large-scale test presented herein. The temperatures behind the façade cladding in [20] and on the surface of the TES-Element were recorded geometrically in the same locations. Comparing both temperature exposures with each other each type of wooden façade cladding from [20] can be applied to the TES-Element if its recorded temperature stays below the temperature recorded on TES-Element in Chapter 3.5.3.3 over the entire testing period (Figure 25).

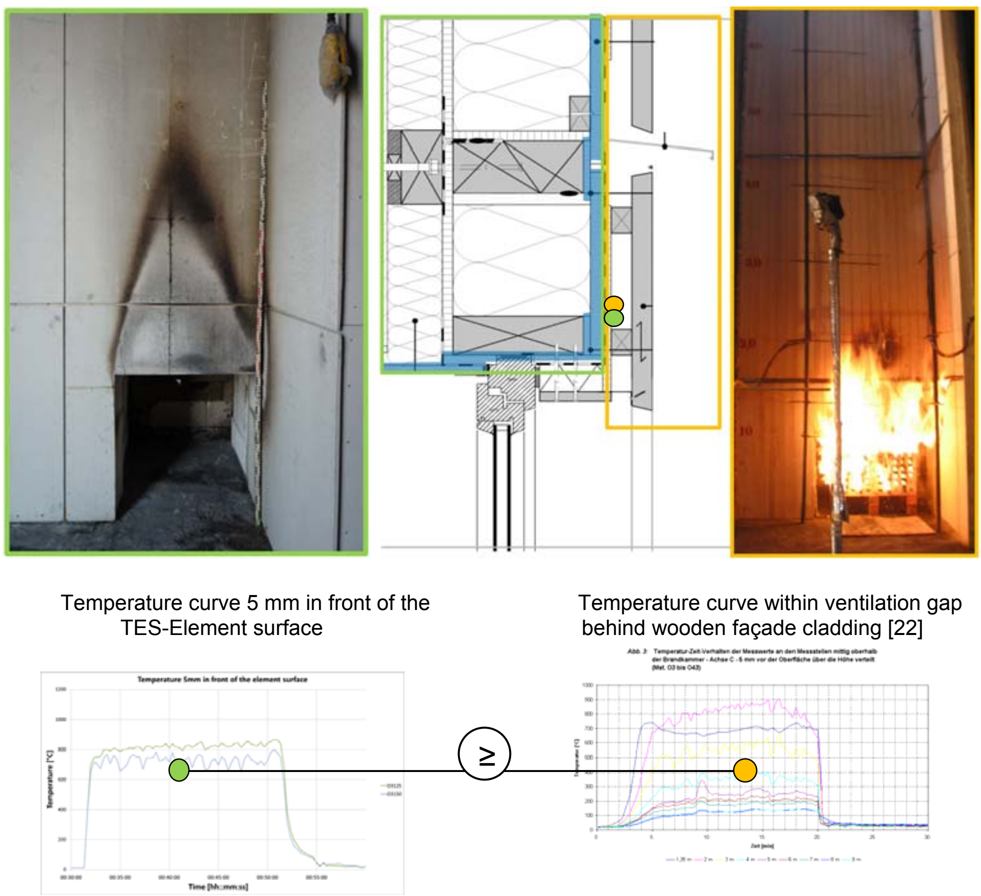


Figure 25 Combining the TES-Façade with wooden façade cladding by comparing temperature test results

2.7. Wall-Floor Joint – Small-scale test

Test construction parameters

Depending on the quality of the existing wall, or if the existing wall is removed, parts of the TES-Façade have to fulfill the requirements of the existing floor (separation function), and the fire and smoke spread paths through the wall-floor joint and the TES-Façade itself have to be blocked by constructive measures (see flame spread path Nr. 4 in Figure 12). The test setup used here resembles the most critical case of fire exposure for the joint area where the existing wall is removed completely.

Test series	No.1	No.2	No.3	No. 4
Connecting system	Coupling beam		Steel bracket	
Fire exposure	60	90	60	90
Installation layer	Yes	No	Yes	No
Variants within a series	Additional mortar groove in coupling beam / No groove		Protection layer below steel bracket: 1x 15 mm GF / 2x 15 mm GF	

Table 9 Small-scale wall-floor testing parameters

Regarding the load-bearing system of the TES-Façades two different connecting systems, the steel bracket (bears horizontal and vertical loads) (1a in Figure 27) and the coupling beam (bears horizontal loads only) (1b), were examined. In the conducted fire tests no additional load was applied to the specimens. For the evaluation of the load bearing capacity the temperature of the steel bracket was measured and the remaining residual cross-sections of timber elements surveyed.
The steel bracket was protected from the bottom-side by gypsum fibre boards (2a), to avoid steel heating, up to critical temperatures. In the second setup with joints between existing floor, coupling beam and TES-Façades, the design was aimed for to get a one dimensional charring from below for the timber members [18] (see Figure 26 - hatched in red and Figure 27-). Therefore an additional wall plate below the horizontal element joint was installed (2b).

To ensure integrity and insulation in the joint-area additional measures were taken. Swelling mortar was filled in the gap between the coupling beam and the existing wall (3b). On the side of the steel bracket the gap between TES-Façade and floor was stuffed with stone wool (3a). The gaps around the bracket have been stuffed with stone wool as well.
The fire exposure time was chosen according to the required fire resistance for floor elements above ground floor in building class GK 4 and 5 of the German building regulation with 60 and 90 minutes.

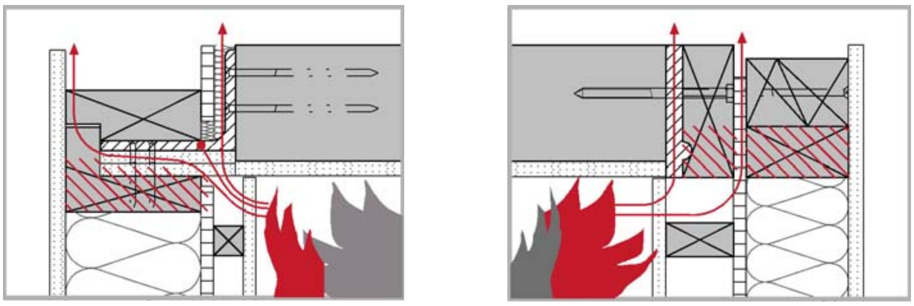


Figure 26 Section specimen wall-floor joint for 60 min test – steel bracket (left) and coupling beam (right). / Critical heat and smoke spread paths, and calculated charred area (red)

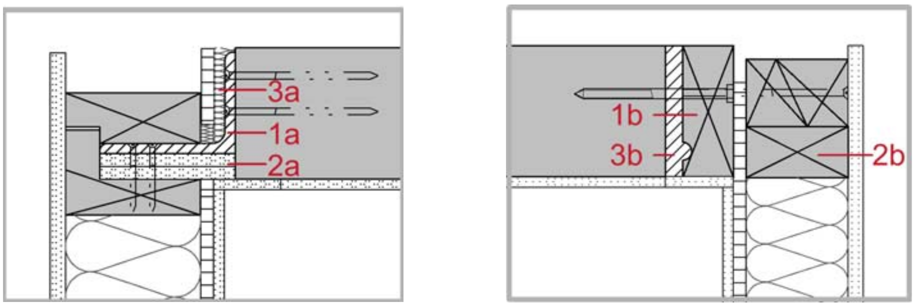


Figure 27 Section specimen wall-floor joint for 90 min test – steel bracket (left) and coupling beam (right)

The main objective of the examination was the assessment of joint permeability and fabric-related gaps between the existing structure and TES-Façade. A burn-through has to be prevented. The second objective is the load-bearing quality of the jointing between elements and ceiling, see Figure 26.

Test procedure

To assess the fire safety of the wall-floor joint area two fire tests were conducted in a small scale test furnace, see Figure 28. The variation in setup can be taken from Table 9, and the exposure level for all fire tests was in accordance to the standard temperature-time curve [16] for 60 and 90 minutes, respectively. After exposure the specimen was lifted out of the furnace and completely extinguished with water.

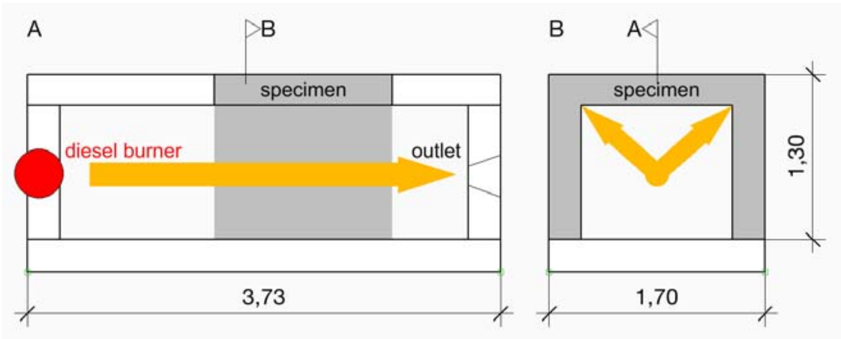


Figure 28 Furnace section – Wall-floor joint area

Test results

“Criterion I (insulation) may be assumed to be satisfied where the average temperature rise over the whole of the non-exposed surface is limited to 140 K, and the maximum temperature rise at any point on the surface does not exceed 180K” [EN 13501-2]. In all series, in total the temperature on the surface did not rise above 120° C and therefore stayed below the required 140°C above the initial temperature. An excerpt of results is given in Figure 29.

“Criterion E (integrity) may be assumed to be satisfied when no sustained flaming or gases occur, or no cracks or openings in excess of dimensions exist” [EN 13501-2]. Although a strong water vapor emission was streaming out through existing gaps, no strong smoke was recognized, for exhaust gas examination, see [27]. The mortar groove in the coupling beam proved to be effective – no water vapor came through, while through the gap without groove water vapor was emitted. Besides the existing gaps no other leakages or cracks occurred. The temperature at all leakages of the element was recorded with mobile thermal sensors. A further evaluation of temperature and residual cross-sections can be found in the test report [27].

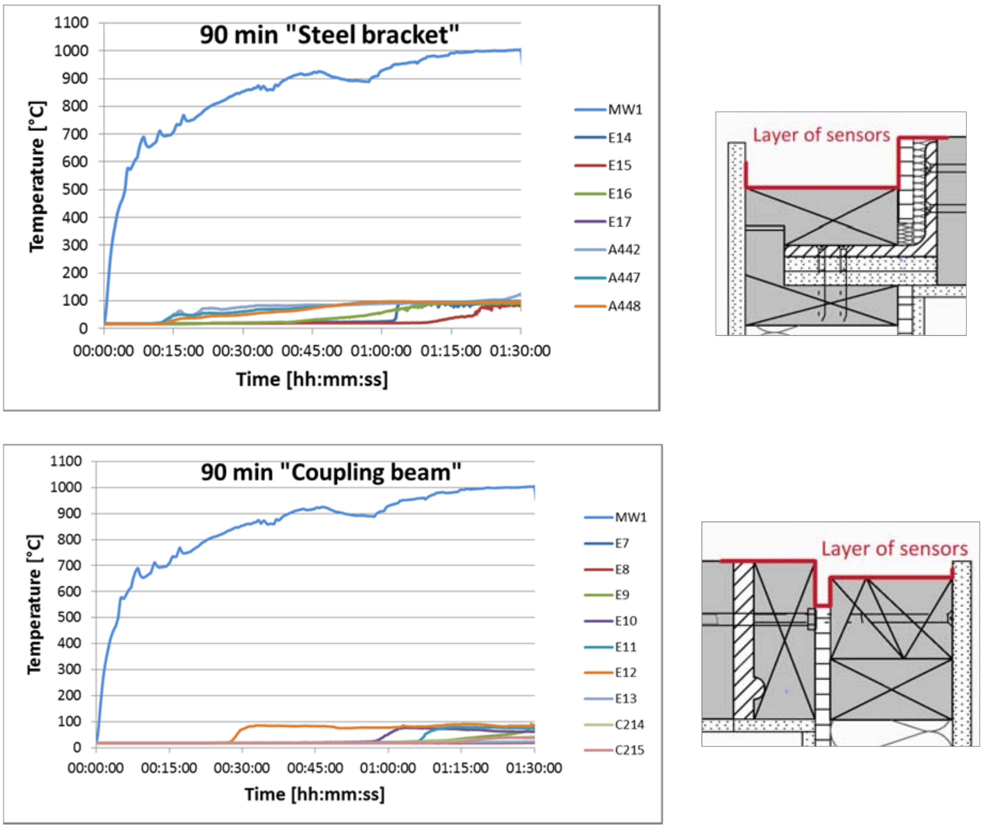


Figure 29 Time-temperature curve of critical spots in layer of sensors. Thermal sensor “MW1” describes furnace temperature (standard temperature-time curve [19]). The other sensors are situated in the layer of sensors (red line in left picture)

Visually the load-bearing parts were still intact. In the 90 minutes test there were slight charring on the side of the coupling beam (Figure 30).

Figure 30 Small-scale fire test – wall-floor – 90 min – almost burn-through between OSB and coupling beam (red circle)

2.8. Conducted fire tests in the context of performance criteria

The following table summarizes how the conducted tests cover the examination of relevant performance criteria:

	Fire out of window (small-scale test)	Fire out of window (large-scale test)	Wall-floor joint (small-scale test)	Others (No test within this project)
Fire overleaping				
No fire spread above more than two stories or below the compartment of fire origin before fire-fighters start extinguishing		x		x [22]
No (relevant) independent fire spread lateral to the primary fire	x	x		x [22]
No re-inflammation and only limited (short term) smouldering	x	x		
Limited fire spread				
- on and within the façade cladding		x		x [22]
- within the TES-Façade	x	x		
- between wall and TES-Façade in the adaption layer	x	x		
- through window junctions and joints	x	x		
- through exterior wall (in combination with existing wall)				x(1)
- resistance/durability of TES-Façade encasing cladding in surface and joints	(x)	x		
fire safety of fire spread path on element junctions wall-ceiling-floor			x	
Fire-fighting operations				
Façade-construction must be extinguishable in all parts (including ventilation gaps and insulation)	(x)	x		
No heavy and large falling off parts, to enable rescue work and secure escape		x	x	
Fire resistance / protection of horizontal anchorage	x	x	x	
Vertically load-stacked variant: Compensating failure of a (middle-) element				x(2)
Fire resistance of the structural connection of façade cladding and TES wall		x	x	
Resistance of the encasing cladding	x	x		
Extinguishable façade (surface and sub-construction) or limitation of fire active area	x	x		x [22]
Smoke				
No heavy and toxic smoke generation		x	x	
Limited smoke spread through element junctions wall-ceiling			x	

Table 10 Performance criteria against conducted tests and other references
(1) Standard construction details [12] or individual producers' technical approvals available. Apply analogue.
(2) Has to be proven through static calculation

2.9. Recommended Fire Safe Construction Details

On the basis of the testing fire safe construction details have been developed, see list below. Some of them are shown in Figure 31, Figure 32 and Figure 33. The figures focus on the connection type "coupling beam", which is the most practical based on the test results.

- As described in earlier chapters most risks can be handled by a closed layer of encasing cladding, which is backed by an additional layer of gypsum board in its jointing areas.
- The entire non-load bearing exterior wall assembly has to be conforming with requirements to separating function, EI. In the area around the window opening enhanced protection measures like non-combustible thermal insulation in the adaption layer and an overlapping encasing cladding shall be applied.
- If the existing wall is removed or not sufficient the fire and smoke spread through the TES-Façade has to be met with additional measures like swelling mortar in gaps next to the ceiling and enlargement of the wall-plate cross-section (alternatively to a multilayer of gypsum boards). The fire safety

requirements to the floor have to be considered. When applying combustible façade claddings fire-stops have to be integrated and the encasing cladding should be adjusted to thermal load-potential of the façade cladding and the resultant temperatures. Choosing a wooden façade cladding a formfitting sheathing fire-stop should be selected as a minimum [22].

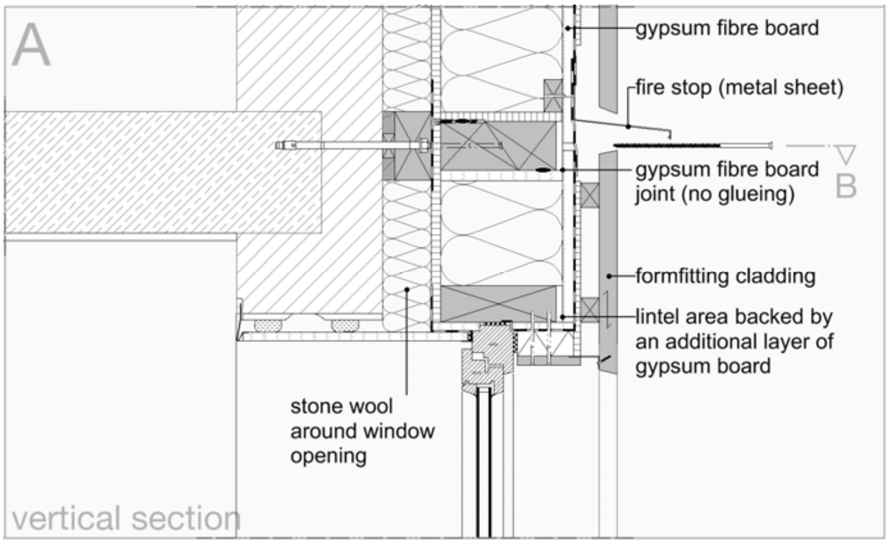


Figure 31 Construction detail with existing wall and window - Vertical section A

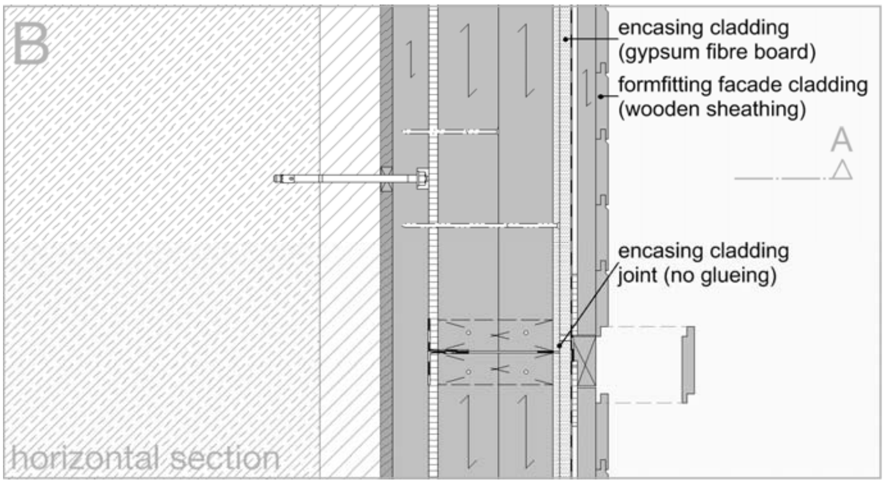


Figure 32 Construction detail with existing wall – Horizontal section B

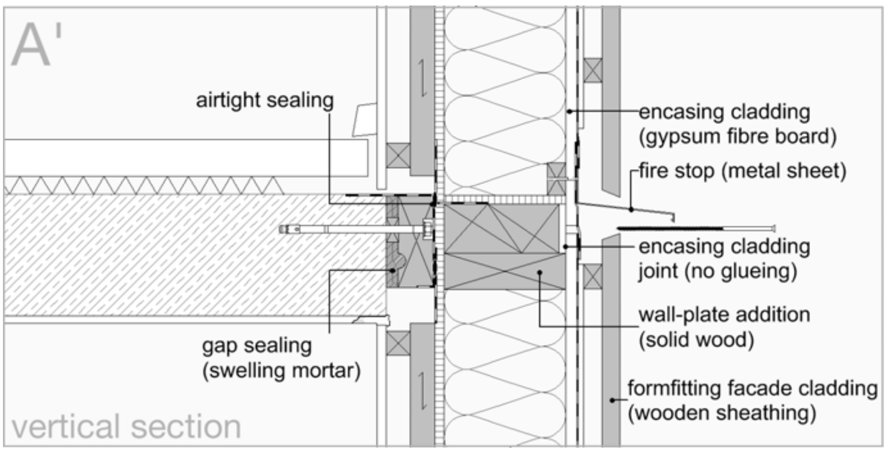


Figure 33 Construction detail existing wall removed - Vertical section A'